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# Annual and Period-of-Record Total Nitrogen Reduction in the Everglades Stormwater Treatment Areas

**Prepared by:**
**Michael J. Chimney Ph.D.**

**Water Quality Treatment Technologies Section**
**Applied Sciences Bureau, Water Resources Division**
**South Florida Water Management District**
**3301 Gun Club Road, West Palm Beach, FL 33406**

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## Introduction

Phosphorus (P) is the primary nutrient responsible for eutrophication of the Florida Everglades. Because of this, the operational focus of the Everglades Stormwater Treatment Areas (hereafter STAs) is on reducing the total P concentration in surface runoff coming from the Everglades Agricultural Area (EAA) (Chimney and Goforth 2001, Sklar et al. 2005). However, these wetlands can provide treatment[1] for other water quality constituents, such as aluminum, iron, total suspended solids, and some forms of nitrogen (N)[2] (Goforth et al. 2004, Gu et al. 2006, Pietro et al. 2006). Nitrogen levels in surface water discharged to some of the District's coastal ecosystems can exceed state water quality standards and/or nutrient criteria defined for these systems (e.g., Janicki Environmental 2003, Buzzelli et al. 2014), which has prompted interest in the treatment efficacy of the STAs for N. This technical publication was prepared in response to this interest and provides scoping-level estimates of the annual (i.e., water year[3]) and period-of-record (POR) reduction of total N (TN) in EAA runoff treated by the STAs. A discussion of the controlling factors and biogeochemical mechanisms involved in TN removal in the STAs is beyond the scope of this report.

## Methods

Calculations of constituent flow-weighted mean (FWM) concentrations, constituent loads and flow volumes at the inflow and outflow sites of each STA (STA-1E, STA-1W, STA-2, STA-3/4, STA-5, STA-6 and STA-5/6) were initially made on a monthly basis using the District's web-based Nutrient Load Tool[4] (NLT) that queried the District's DBHYDRO hydrologic and water quality database (see **Table 1** for details). The inflow and outflow sites and corresponding Dbkey(s)[5] used for each STA in this analysis were the same sites and Dbkeys used by the District to evaluate total P treatment in the STAs. The NLT aggregates data from multiple inflow sites in an STA into a single "inflow" category and multiple outflow sites into a single "outflow" category in the monthly output it generates. Monthly output was subsequently aggregated on annual and POR bases using an Excel workbook. Total N FWM concentrations and loads at the start of the data record for each STA were calculated as the sum of nitrate + nitrite (NOX) and total Kjeldahl nitrogen (TKN) FWM concentrations and loads, respectively using Excel. The District's Chemistry Laboratory discontinued TKN analyses in either 2014 or 2015, depending on the STA and sample site (**Table 1**),

[1] Treatment is defined as the reduction in constituent concentration or load (i.e., mass) that takes place as water flows through a STA.

[2] The STAs are very efficient at treating dissolved inorganic forms of N, but much less so for dissolved organic N fractions. Dissolved organic N can constitute 50% or more of the inflow total N load to the STAs (CH2MHill, 2008).

[3] Annual calculations were based on the District's water year (WY), which runs from May 1 to April 30 of the following calendar year.

[4] http://my.sfwmd.gov/NutrientLoadWebApp. Inflow and outflow site designations, DB flow keys for these sites, and constituent test numbers used to query DBHydro are specified in "workspaces" within the NLT. These workspaces (see **Table 1**) are clonable and shared with other NLT users. Query results generated by the NLT for a workspace are output as an Excel workbook. Computations are limited to constituent concentrations and loads in surface water; the NLT does not consider contributions from precipitation, dry deposition, or groundwater infiltration/exfiltration.

[5] A Dbkey is an index value that associates a unique subset of hydrologic or water quality records with a particular sample site in the DBHYDRO database.

and transitioned to direct measurements of TN[6]. This analytical change is reflected in the TN computations in the Excel workbooks. The start date for each STA in this analysis was the first month in which both NOX and TKN were measured at all inflow and outflow sample sites that had flow data (see **Table 1**).

Annual TN FWM concentrations and loads were calculated only for full water years with 12 months of data, while POR calculations also included months in partial water years at the beginning and end of the data record[7]. Total N treatment performance was evaluated based on the reduction in FWM concentrations and loads between the inflow and outflow sites of each STA.

Separate analyses of TN FWM concentrations and loads were made for STA-5 and STA-6 over the periods before these STAs were combined into STA-5/6, and for STA-5/6 for the period after the merger. The STA-5 analysis was restricted to Flow-ways 1, 2 and 3 with an end date before cells in the Compartment C buildout came online (December 2012; **Table 1**). The STA-6 analysis was restricted to Cells 3 and 5 over the period that ended when water quality sampling at the G600 inflow pump station stopped (August 2007) and before inflow to the STA was switched from U.S. Sugar Corporation's Unit 2 to the L3 Canal. STA-5/6 included data from all eight flow-ways with a start date when NOX and TKN measurements were initiated at new cells in the Compartment C buildout (September 2012).

## Results

With the exception of STA-6 (see below), there was, at best, only a moderate reduction (< 50%) in TN FWM concentration and load at each STA over its POR (**Table 2**). The POR reduction in FWM TN concentration ranged from 14% at STA-5 to 45% at STA-3/4 with a collective reduction over all the STAs of 38%. The corresponding POR reduction in TN load ranged from 12% at STA-5/6 to 61% at STA-6 with a collective reduction over all the STAs of 38%. The calculation of load reduction is a function of the difference in concentration and flow volume measured at the inflow and outflow. Note that inflow-to-outflow difference in POR flow volume ranged from only -7 to 8% at all STAs with the exception of STA-6 where the POR difference in flow volume was 43%[8]. Even if there is no decrease in constituent concentration from inflow to outflow, a reduction in flow volume at the outflow would result in a calculated constituent load reduction. The 61% TN load reduction calculated for STA-6 was attributed, in part, to large seepage losses between inflow and outflow and not a greater TN concentration reduction compared to the other STAs; STA-6 only had a 32% reduction in POR FWM TN concentration. If the POR load reduction at STA-6 is discounted, the next largest POR load reduction was 47% at STA-3/4.

There were, in general, only moderate differences (< 50%) among the STAs in their reduction of annual TN FWM concentrations and loads (**Fig. 1** and **Table 2**). As with the POR load reductions discussed above, annual TN load reductions in STA-6 were biased high compared to the other

[6] The change in procedure for determining TN concentration is described in SFWMD (2015). The new direct measurement method for TN produces results that are comparable to summing NOX and TKN concentrations.

[7] For example, the analysis start date for STA-5/6 is September 2012 (**Table 1**) which is in WY2013. However, because there weren't 12 months of data from WY2013 available for this STA, annual calculations for WY2013 were not made (**Table 2**), while the range of data used for STA-5/6 POR calculations started with the September 2012 data.

[8] STA-6 had a substantial seepage loss component in its water budget (e.g., Huebner 2008), which would account for the consistently large imbalance in annual and POR flow volumes between its inflow and outflow sites.

STAs due to consistently large annual seepage losses in STA-6. Annual TN concentration reduction over all the STAs was strongly correlated with inflow TN concentration (r = 0.71; **Fig. 2**). However, while statistically significant, there was only a weak linear relationship between TN load reduction and inflow TN load (r = 0.26). The STAs, in general, are efficient at removing dissolved inorganic N fractions. The composition of TN in STA effluent was usually composed primarily of particulate N and dissolved organic N.

The Excel workbooks generated for this report are archived in a Morpho data package[9] that is stored in the District's Metacat data repository.

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[9] Morpho data package: *Stormwater Treatment Areas (STAs)_Annual & POR total N reduction (WY2001 - WY2016)*.

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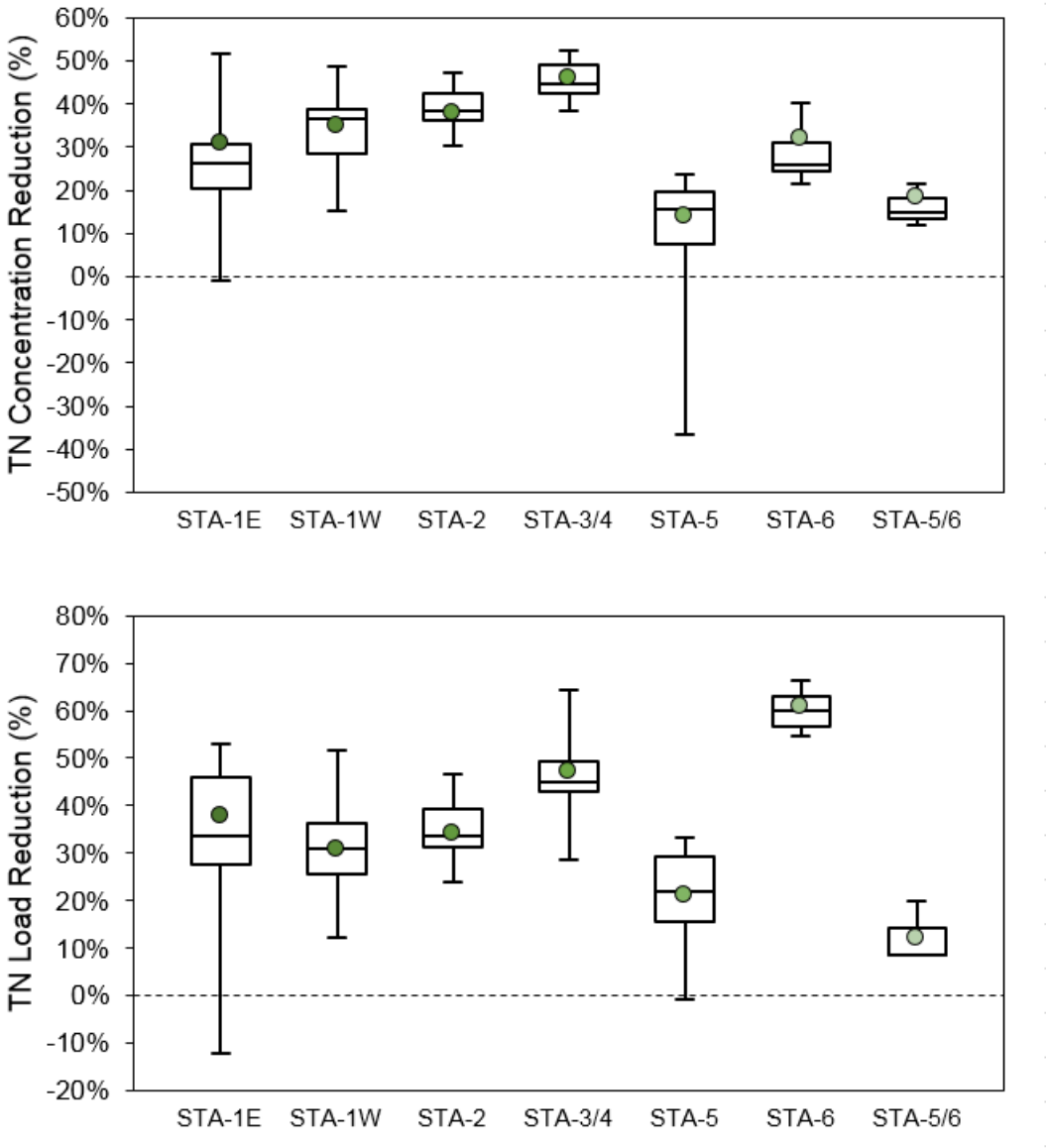


**Figure 1**. Box plots of percent reduction in annual total nitrogen FWM concentrations (top) and loads (bottom) in the Everglades Stormwater Treatment Areas. Box plot legend: horizontal line within box = median of data distribution (50$^{th}$ percentile), top of box = 75$^{th}$ percentile, bottom of box = 25$^{th}$ percentile, spreader bars = minimum and maximum removal values. Solid circles are average removal values over the POR for each STA.

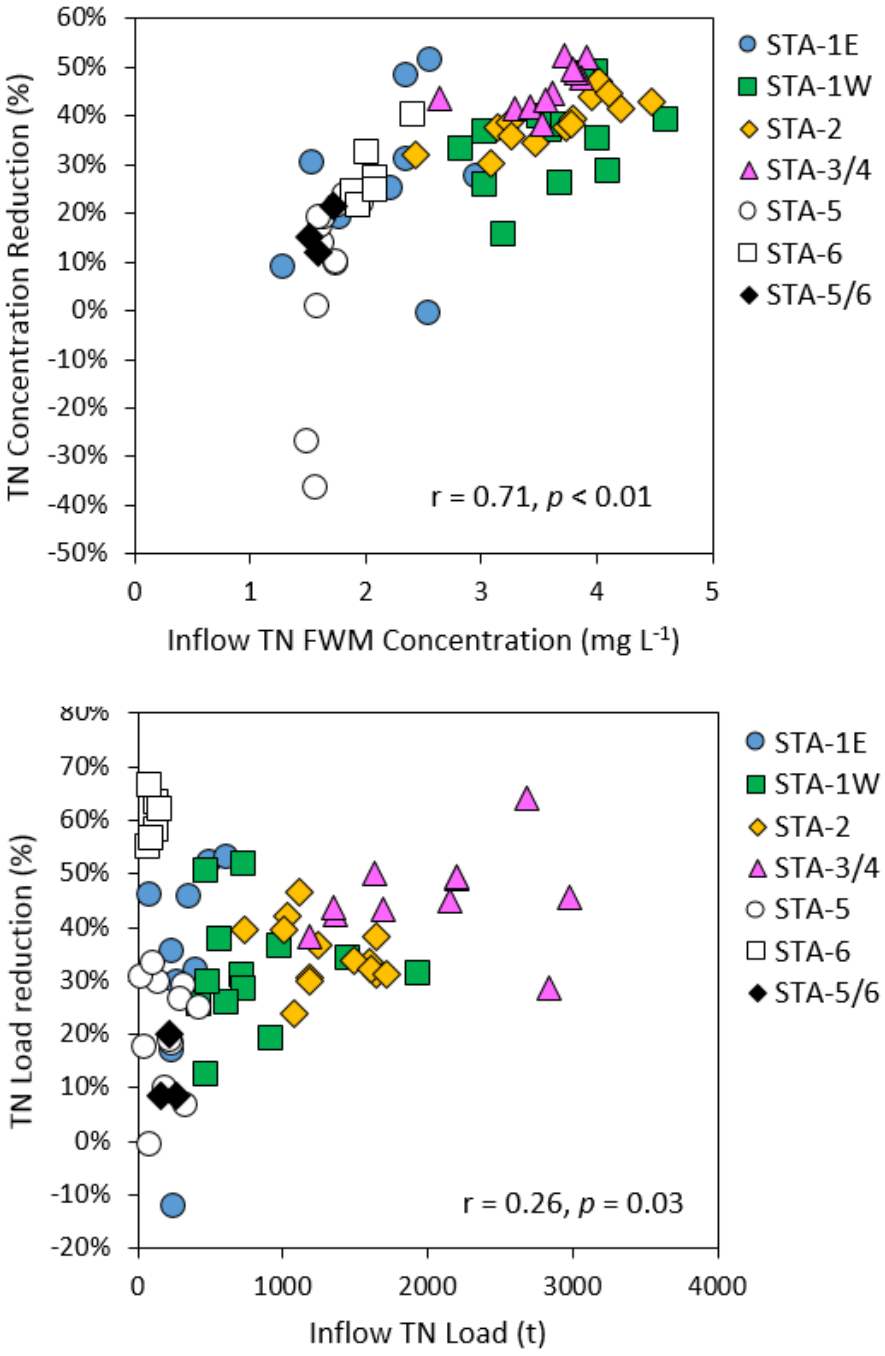


**Figure 2**. Scatter plots of reduction in annual total nitrogen FWM concentrations and loads versus annual inflow TN FWM concentrations and inflow loads, respectively, in the Everglades Stormwater Treatment Areas.

**Table 1**. Nutrient load workspaces used to query total nitrogen (TN) data, Excel workbooks, and other details associated with the computation of TN flow-weighted mean concentrations, TN loads, and flow volumes in the Everglades Stormwater Treatment Areas.

| STA | Nutrient Load Tool Workspace[a] | Excel Workbook[b] | Inflow Sites | Outflow Sites | Analysis Start Date | Analysis End Date | TN Measurements Initiated |
|---|---|---|---|---|---|---|---|
| STA-1E | TN_STA-1E | TN_STA-1E_Summary.xlsx | S319, S361, G311 (with positive flow) | G311 (with negative flow), S362 | October 2005 | December 2016 | October 2015 |
| STA-1W | TN_STA-1W | TN_STA-1W_Summary.xlsx | G302 | G310, G251 (aka ENR012) | October 2002 | December 2016 | September or October 2015 depending on site |
| STA-2[c] | TN_STA-2_Before Comp B<br>TN_STA-2_After Comp B | TN_STA-2_Summary.xlsx | Before Comp. B: S6, G328;<br>After Comp. B: S6, G328, G434, G435 | Before Comp. B: G335;<br>After Comp. B: G335, G436 | July 2001 - before Comp. B;<br>September 2012 - after Comp. B | August 2012 - before Comp. B;<br>December 2016 - after Comp. B | September or December 2015 depending on site |
| STA-3/4 | TN_STA-3/4 | TN_STA-34_Summary.xlsx | G370, G371 | G376A, G376B, G376C, G376D, G376E, G376F, G379A, G379B, G379C, G379D, G379E, G381A, G381B, G381C, G381D, G381E, G381F | October 2004 | December 2016 | December 2015 |
| STA-5[d] | TN_STA-5_Before FW3<br>TN_STA-5_After FW3 | TN_STA-5_Summary.xlsx | Before FW3: G342A, G342B, G342C, G342D;<br>After FW3: G342A, G342B, G342C, G342D, G342E, G342F | Before FW3: G344A, G344B, G344C, G344D;<br>After FW3: G344A, G344B, G344C, G344D, G344E, G344F | April 2000 - before Flow-way 3;<br>September 2008 - after Flow-way 3 & before Comp. C | August 2008 - before Flow-way 3;<br>December 2012 - after Flow-way 3 & before Comp. C | Analysis end date preceded the start of TN measurements by the District at this STA. |
| STA-6 | TN_STA-6 | TN_STA-6_Summary.xlsx | G600 | G354A, G354B, G354C, G393A, G393B, G393C | August 2000 | August 2007 - last WQ data from G600 & before inflow was changed to the L-3 Canal | Analysis end date preceded the start of TN measurements by the District at this STA. |
| STA-5/6[e] | TN_STA-5/6 | TN_STA-56_Summary.xlsx | G342A, G342B, G342C, G342D, G508, G342O, G406 | G344A, G344B, G344C, G344D, G344E, G344F, G344G, G344H, G344I, G344J, G344K, G352A, G352B, G352C, G354A, G354B, G354C, G393A, G393B, G393C | September 2012 | November 2016 | July 2014 |

[a]Workspace(s) used to query DBHydro; [b]Excel workbooks have metadata with details on TN computations; [c]TN reduction in STA-2 was computed for two periods: (1) Flow-ways 1, 2, 3 and 4 before cells in the Compartment B build-out came online and (2) all flow-ways after the Compartment B build-out was online; [d]TN reduction in STA-5 was computed for two periods: (1) Flow-ways 1 and 2 before Flow-way 3 was online and (2) Flow-ways 1, 2, and 3 after Flow-way 3 went online and before the Compartment C buildout was operational; [e]STA-5/6 computations included all 8 flow-ways and started when new cells in the Compartment C buildout were operational.

**Table 2**. Annual and period-of-record inflow and outflow total nitrogen (TN) flow-weighted mean (FWM) concentrations, TN loads, and flow volumes in the Everglades Stormwater Treatment Areas.

| | | TN FWM Concentration | | | TN Load | | | Flow Volume | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | IN | OUT | | IN | OUT | | IN | OUT | |
| STA | Period | (mg $L^{-1}$) | (mg $L^{-1}$) | Δ[a] | (t) | (t) | Δ | ($hm^3$) | ($hm^3$) | Δ |
| STA-1E | WY2007 | 2.96 | 2.15 | 27% | 406 | 276 | 32% | 137 | 128 | 6% |
| | WY2008 | 1.29 | 1.18 | 9% | 247 | 205 | 17% | 191 | 174 | 9% |
| | WY2009 | 2.56 | 1.24 | 52% | 495 | 238 | 52% | 193 | 191 | 1% |
| | WY2010 | 2.55 | 2.57 | -1% | 254 | 285 | -12% | 100 | 111 | -11% |
| | WY2011 | 1.77 | 1.44 | 19% | 86 | 46 | 46% | 48 | 32 | 33% |
| | WY2012 | 2.11 | 1.59 | 25% | 235 | 152 | 35% | 112 | 96 | 14% |
| | WY2013 | 1.55 | 1.08 | 30% | 280 | 197 | 30% | 181 | 182 | -1% |
| | WY2014 | 2.23 | 1.67 | 25% | 350 | 256 | 27% | 157 | 154 | 2% |
| | WY2015 | 2.36 | 1.63 | 31% | 362 | 197 | 46% | 153 | 121 | 21% |
| | WY2016 | 2.35 | 1.22 | 48% | 616 | 290 | 53% | 262 | 237 | 9% |
| | POR | 2.19 | 1.52 | 31% | 3,869 | 2,454 | 37% | 1,763 | 1,620 | 8% |
| STA-1W | WY2004 | 4.02 | 2.61 | 35% | 1,451 | 957 | 34% | 361 | 367 | -2% |
| | WY2005 | 4.61 | 2.82 | 39% | 1,941 | 1,333 | 31% | 421 | 473 | -12% |
| | WY2006 | 4.10 | 2.93 | 29% | 722 | 498 | 31% | 176 | 170 | 3% |
| | WY2007 | 3.20 | 2.70 | 15% | 480 | 421 | 12% | 150 | 156 | -4% |
| | WY2008 | 3.03 | 2.25 | 26% | 435 | 324 | 25% | 143 | 144 | -1% |
| | WY2009 | 3.60 | 2.27 | 37% | 731 | 524 | 28% | 203 | 231 | -14% |
| | WY2010 | 3.70 | 2.73 | 26% | 922 | 746 | 19% | 249 | 273 | -9% |
| | WY2011 | 3.68 | 2.27 | 38% | 571 | 356 | 38% | 155 | 157 | -1% |
| | WY2012 | 4.00 | 2.05 | 49% | 478 | 238 | 50% | 119 | 116 | 3% |
| | WY2013 | 3.04 | 1.92 | 37% | 623 | 463 | 26% | 205 | 240 | -17% |
| | WY2014 | 3.51 | 2.11 | 40% | 986 | 628 | 36% | 281 | 297 | -6% |
| | WY2015 | 2.83 | 1.90 | 33% | 490 | 345 | 30% | 173 | 182 | -5% |
| | WY2016 | 3.88 | 2.00 | 48% | 740 | 357 | 52% | 191 | 203 | -6% |
| | POR | 3.56 | 2.31 | 35% | 11,816 | 8,236 | 30% | 3,323 | 3,506 | -6% |
| STA-2 | WY2003 | 3.08 | 2.15 | 30% | 1,074 | 817 | 24% | 349 | 380 | -9% |
| | WY2004 | 3.74 | 2.34 | 37% | 1,185 | 821 | 31% | 317 | 351 | -11% |
| | WY2005 | 4.21 | 2.47 | 41% | 1,644 | 1,129 | 31% | 390 | 458 | -17% |
| | WY2006 | 4.47 | 2.55 | 43% | 1,640 | 1,013 | 38% | 367 | 398 | -8% |
| | WY2007 | 3.95 | 2.21 | 44% | 1,114 | 594 | 47% | 282 | 268 | 5% |
| | WY2008 | 4.01 | 2.12 | 47% | 1,027 | 594 | 42% | 256 | 280 | -9% |
| | WY2009 | 3.79 | 2.30 | 39% | 1,181 | 826 | 30% | 311 | 359 | -15% |
| | WY2010 | 3.77 | 2.33 | 38% | 1,603 | 1,065 | 34% | 425 | 458 | -8% |
| | WY2011 | 3.46 | 2.26 | 35% | 740 | 446 | 40% | 214 | 197 | 8% |
| | WY2012 | 4.11 | 2.27 | 45% | 1,006 | 609 | 40% | 245 | 268 | -10% |
| | WY2013 | 3.15 | 1.96 | 38% | 1,250 | 793 | 37% | 397 | 404 | -2% |
| | WY2014 | 3.25 | 1.99 | 39% | 1,489 | 988 | 34% | 459 | 496 | -8% |
| | WY2015 | 2.43 | 1.66 | 32% | 1,605 | 1,087 | 32% | 660 | 657 | 0% |
| | WY2016 | 3.26 | 2.09 | 36% | 1,722 | 1,183 | 31% | 529 | 568 | -7% |
| | POR | 3.49 | 2.15 | 38% | 20,317 | 13,325 | 34% | 5,818 | 6,198 | -7% |

**Table 2**. (Continued).

| | | TN Concentration | | | TN Load | | | Flow Volume | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | IN | OUT | | IN | OUT | | IN | OUT | |
| STA | Period | (mg $L^{-1}$) | (mg $L^{-1}$) | Δ[a] | (t) | (t) | Δ | ($hm^3$) | ($hm^3$) | Δ |
| STA-3/4 | WY2006 | 3.30 | 1.93 | 42% | 2,838 | 2,022 | 29% | 861 | 1,050 | -22% |
| | WY2007 | 3.43 | 1.99 | 42% | 1,688 | 957 | 43% | 493 | 481 | 2% |
| | WY2008 | 3.53 | 2.17 | 38% | 1,362 | 784 | 42% | 386 | 361 | 7% |
| | WY2009 | 3.92 | 1.88 | 52% | 2,153 | 1,182 | 45% | 550 | 630 | -15% |
| | WY2010 | 3.87 | 2.02 | 48% | 2,984 | 1,625 | 46% | 772 | 805 | -4% |
| | WY2011 | 3.62 | 2.00 | 45% | 1,354 | 764 | 44% | 374 | 382 | -2% |
| | WY2012 | 3.55 | 2.01 | 43% | 1,181 | 731 | 38% | 333 | 363 | -9% |
| | WY2013 | 3.72 | 1.77 | 52% | 2,204 | 1,119 | 49% | 592 | 633 | -7% |
| | WY2014 | 3.82 | 1.96 | 49% | 2,202 | 1,116 | 49% | 577 | 570 | 1% |
| | WY2015 | 2.64 | 1.49 | 44% | 1,637 | 819 | 50% | 619 | 550 | 11% |
| | WY2016 | 3.79 | 1.92 | 49% | 2,681 | 957 | 64% | 708 | 500 | 29% |
| | POR | 3.43 | 1.88 | 45% | 25,123 | 13,233 | 47% | 7,320 | 7,033 | 4% |
| STA-5 | WY2001 | 1.49 | 1.90 | -27% | 93 | 94 | -1% | 62 | 49 | 21% |
| | WY2002 | 1.64 | 1.41 | 14% | 322 | 229 | 29% | 196 | 162 | 18% |
| | WY2003 | 1.58 | 1.57 | 1% | 332 | 310 | 6% | 210 | 198 | 6% |
| | WY2004 | 1.62 | 1.34 | 17% | 306 | 225 | 26% | 189 | 168 | 11% |
| | WY2005 | 1.65 | 1.34 | 19% | 244 | 200 | 18% | 148 | 150 | -1% |
| | WY2006 | 1.60 | 1.29 | 19% | 426 | 321 | 25% | 267 | 248 | 7% |
| | WY2007 | 1.98 | 1.55 | 22% | 147 | 103 | 30% | 74 | 67 | 10% |
| | WY2008 | 1.57 | 2.15 | -36% | 27 | 19 | 31% | 17 | 9 | 49% |
| | WY2009 | 1.77 | 1.39 | 22% | 197 | 178 | 10% | 111 | 128 | -15% |
| | WY2010 | 1.76 | 1.59 | 10% | 231 | 188 | 19% | 132 | 118 | 10% |
| | WY2011 | 1.75 | 1.58 | 10% | 58 | 47 | 18% | 33 | 30 | 9% |
| | WY2012 | 1.82 | 1.39 | 24% | 107 | 71 | 33% | 59 | 52 | 12% |
| | POR | 1.66 | 1.44 | 14% | 2,595 | 2,053 | 21% | 1,561 | 1,429 | 8% |
| STA-6 | WY2002 | 2.09 | 1.52 | 27% | 137 | 50 | 63% | 66 | 33 | 50% |
| | WY2003 | 1.89 | 1.43 | 24% | 131 | 55 | 58% | 69 | 39 | 44% |
| | WY2004 | 2.42 | 1.45 | 40% | 157 | 60 | 62% | 65 | 41 | 36% |
| | WY2005 | 1.94 | 1.53 | 21% | 82 | 37 | 55% | 42 | 24 | 42% |
| | WY2006 | 2.01 | 1.36 | 32% | 100 | 44 | 56% | 50 | 32 | 36% |
| | WY2007 | 2.10 | 1.58 | 25% | 84 | 28 | 66% | 40 | 18 | 56% |
| | POR | 2.09 | 1.43 | 32% | 780 | 302 | 61% | 372 | 211 | 43% |
| STA-5/6 | WY2014 | 1.72 | 1.35 | 21% | 219 | 175 | 20% | 128 | 130 | -2% |
| | WY2015 | 1.59 | 1.40 | 12% | 164 | 149 | 9% | 103 | 107 | -4% |
| | WY2016 | 1.51 | 1.29 | 15% | 271 | 247 | 9% | 179 | 192 | -8% |
| | POR | 1.55 | 1.27 | 18% | 933 | 818 | 12% | 603 | 643 | -7% |

[a]Reduction/change (Δ) between STA inflow and outflow was calculated as (inflow-outflow)/inflow and expressed as a percent. Positive Δ values indicate a decrease in concentration, load, or flow volume from inflow to outflow, whereas negative Δ values indicate an increase in concentration, load or flow volume from inflow to outflow.