Water Quality Assessment of the Interim Operations Plan: Phosphorus Concentrations and Loads

prepared for

U.S. Department of the Interior
Everglades National Park

By

William W. Walker, Jr., Ph.D., Environmental Engineer
1127 Lowell Road, Concord, Massachusetts 01742
978-369-8061, bill@wwwalker.net

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1.0 Introduction

Changes in the spatial and seasonal distribution of inflows to Everglades National Park (ENP) were made in 1999 to preserve habitat for the Cape Sable Sea Sparrow (CSSS), an Endangered Species nesting in the Park. The "Interim Structural and Operational Plan" (ISOP) in 1999 and "Interim Operations Plan" in 2002 (IOP) followed a long series of regional water-management schemes tested since the 1960's to deliver flow to ENP while providing flood control and water supply benefits to urban and agricultural areas in South Florida. The last major change was made in 1987, when operations evolved from a flow-thru mode, with inflow structures along the Tamiami Trail left open, into a rainfall-driven mode, with inflow structures regulated based upon antecedent rainfall in Water Conservation Area 3A (WCA-3A) in an attempt to restore natural flows and hydroperiods. ISOP/IOP measures to protect the CSSS habitat and contemporaneous changes in regional water management (e.g., initial phases of the C111 buffer project) may have had secondary (positive or negative) impacts on ENP hydrology, water quality, vegetation, and wildlife.

This report evaluates changes in phosphorus concentrations and loads at structures sites located in and around WCA-3A and ENP following implementation of the IOP (term used below to represent both ISOP & IOP). Nutrient enrichment is a major regional concern because of documented impacts on water quality and ecological communities (SFWMD, 2003). Changes potentially attributed to the IOP are assessed in the context of other variations associated with climate, other changes in water management, and water quality trends in basins discharging into WCA-3A, the immediate source of flow discharged into ENP's Shark River Slough.

The analysis is based upon hydrologic and water quality data collected primarily by the South Florida Water Management District (SFWMD) between 1994 and 2003 (Figure 1). A relatively simple statistical procedure is applied to identify monitoring sites where changes in average flows, concentrations, or loads are likely to have occurred following IOP implementation in late 1999. The procedure accounts for background variations associated with rainfall. More detailed analyses and interpretations of the results are performed on a regional basis to further describe the changes and assess the likelihood of causal linkages to the IOP, as opposed to other anthropogenic or natural factors. Three regions are considered: WCA-3A, Shark River Slough, and the Taylor Slough/Eastern Panhandle basins. Results are discussed in relation to compliance with ENP inflow P concentration limits specified under the State/Federal consent decree (Hoeveler, 1991). Recommendations are made with respect to future operation, monitoring, and assessment.

Supporting data are summarized and graphed in the Appendix. Further details on the data compilation and statistical analyses are posted at http://www.wwwalker.net/iop .

<< Figure 1

2.0 Data Compilation

Variations in WCA-3A stage and basin rainfall between 1984 and 2003 are shown in Figure 2. These are two of the primary factors controlling the water budget of WCA-3A and discharges into ENP Shark River Slough (SRS). Basin rainfall is an average of data from monitoring sites located in and around the WCA's, EAA, and C139 basin (Figure 1). This region represents most of the "watershed" above the S12/S333 inflow structures to SRS.

<< Figure 2

Changes potentially attributed to the IOP have been identified by comparing data from the 1994-1999 and 2000-2003 periods. Rainfall ranged from 50-70 inches/year in the pre-IOP period, as compared with 40-60 inches/year in the IOP period. Because of the difference in rainfall regimes, effects of IOP cannot be assessed by a direct comparison of monitoring data from the two periods. Adjustment for rainfall variations is essential to distinguish long-term changes potentially related to IOP from short-term climatologic variations.

Data prior to 1994 are less relevant as a frame of reference for evaluating IOP impacts because regional water management schemes were not typical of subsequent years and WCA-3A, in particular, was regulated at lower water levels. Best Management Practices (BMP's) implemented in the Everglades Agricultural Area (EAA) during the mid 1990's reduced phosphorus loads to the WCA's (SFWMD, 2003). These reductions may have influenced phosphorus concentrations and loads at ENP inflow structures. Focusing on the 1994-2003 post-BMP period enables separation of potential BMP and IOP effects. As demonstrated below, there were no apparent trends in phosphorus loads from EAA structures into WCA-3A or into WCA-3A as a whole over the 1994-2003 period, although there were apparent trends in loads from specific sources outside of the EAA (increasing at S9 and S140, decreasing at the S11's and G155).

Phosphorus concentration data collected at canal and marsh sites are derived from SFWMD's long-term water quality monitoring network (Figure 1). Concentrations were measured in grab samples collected biweekly at structures and monthly at marsh sites. Weekly flow-proportional composite samples were typically collected at pump stations and supplemented with grab samples. Phosphorus concentrations below the detection limit (2 – 4 ppb) have been set equal to the detection limit prior to computing loads and performing statistical analyses. Results are subject to limitations associated with laboratory phosphorus analyses in the low concentration range (< 10 ppb), including (a) expected low precision of individual sample results at values approaching the detection limit; (b) possible negative bias in the data during portions of 1996 and 1997, as identified under FDEP's Everglades Round Robin program (Walker, 1999); and (c) decrease in detection limit from 4 ppb to 2 ppb in 2002, which may have influenced comparisons of data from the pre-IOP and IOP periods.

Water quality data supplied by the Corps of Engineers Jacksonville District (Anamar, Inc. et al, 2003) are based upon daily composite, weekly composite, and/or grab samples collected at structures and pump stations in the L31N/C111 basin between 2001 and 2003. Because of the limited period of record, these data are used to evaluate concentration dynamics in detention areas associated with the C111 buffer project, but not in comparisons of the pre-IOP and IOP periods.

Daily flow data have been obtained from regional databases (SFWMD's DBHYDRO and ENP's FOREVER). Figure 3 shows water year (June-May) flow time series at gauging sites in Shark River Slough and the L31N/C111 basin. Flows are plotted on the same scale at each site. This provides general perspective on spatial and temporal variations in flow during the study period.

<< Figure 3

Flow and concentration data have been integrated to produce daily time series of phosphorus concentrations and loads at each monitored structure or pump station where both flow and water quality are monitored. The integration has been performed by interpolating concentrations between adjacent grab-sampling dates with positive flow. When available, weekly flow-weighted composite samples have been used in place of grabs. Daily flows and loads have been summed on monthly and yearly bases to support statistical modeling of IOP effects. Several composite flows are computed by combining results from individual structures. For example, the 'S12'X term is the sum of values from the individual S12 structures. Table 1 defines the individual and composite structures and lists average flows, concentrations, loads in the pre-IOP and IOP periods.

<< Table 1

For consistency with hydrologic and biological IOP assessments being conducted independently, annual totals have been computed on a water-year basis (June – May; i.e. Water Year 2003 extends from June 1, 2002 through May 31, 2003). This convention roughly separates the annual hydrographs so that the wet season starts at the beginning of each water year. Water years 1994-2003 extend from June 1,1993 through May 31, 2003. Repeating the analysis with a May-April water year definition (used for tracking BMP performance in the EAA) does not influence the basic conclusions.

The flow, concentration, and load data are summarized and plotted in the Appendix. Further details are posted at http://www.wwalker.net/iop.

3.0 Screening Procedure

Shifts in mean flow, concentration, or load have been identified by comparing yearly data before and during IOP using graphical and statistical techniques. Identifying changes specifically related to IOP is difficult in the presence of background variability attributed to variety natural and anthropogenic factors, as well as to sampling variability. Background variance in structure flows and P loads is correlated with basin rainfall at most structures. A regression model of the following form has been used as a screening procedure to test for shifts in the long-term mean between the two time periods in the presence of natural variations associated with rainfall and other random factors:

$$Y = B_0 + B_1 \text{ Rainfall} + B_2 \text{ IOP} + \text{Error}$$

where,

Y = response variable (water year flow, load, flow-weighted-mean concentration)

Rainfall = basin average rainfall (inches)

IOP = dummy variable (= 0 before IOP, = 1 during IOP).

Error = random variance attributed to sampling and other factors

The rainfall term represents year-to-year variations in Y that are correlated with rainfall. The IOP term represents a hypothetical shift in the mean value of Y after IOP implementation. While the model accounts for correlations with rainfall, it does not require such correlations to be present. If $B_1=0$, the model condenses to a direct comparison of pre-IOP and post-IOP means, similar to Student's t-test applied directly to the observed values (Snedecor & Cochran, 1989).

The likelihood that a shift in the long-term mean occurred after IOP implementation is assessed by testing a two-tailed null hypothesis ($B_2 = 0$) using the mean and standard error of B_2 and the degrees freedom associated with the regression (10 years - 3 coefficients = 7). Apparent differences in the mean are classified as follows: (1) not significant ($p > 0.15$); (2) mildly significant ($p = 0.05 – 0.15$); (3) significant ($p < 0.05$). Because the p levels used to define these categories are somewhat arbitrary, the categories are used for summary and display purposes only. For a one-tailed null hypothesis, the quantity p/2 estimates the probability that the true change was in the opposite direction from the apparent change indicated by the sign of the regression coefficient. For example, with $B_2 > 0$ (indicating an increase under IOP) and $p = 0.20$, there would be a 10% chance that mean actually decreased.

Classification of a result as "not significant" indicates that any change that may have occurred in the long-term mean was not large enough to be detected in the presence of background variations. It does not prove that no change occurred. Similarly, classification of a result as "significant" indicates that a change in the mean value probably occurred between the two periods. Any causal linkages to IOP would be drawn from further analyses and interpretations.

The model allows adjustment of the observed time series to account for rainfall variations:

$$\text{Adjusted } Y = Y + B_1 \left(\text{Mean Rainfall} - \text{Yearly Rainfall} \right)$$

The mean rainfall (54 inches/yr) is computed for the entire 1994-2003 period. Differences between the IOP and pre-IOP periods are expressed in absolute terms (B2) and as a percentage of the pre-IOP, rainfall-adjusted mean.

A simpler procedure for identifying differences between pre-IOP and IOP means is to regress the response variable against rainfall for the pre-IOP period only. The regression model is subsequently applied to the IOP period and differences between observed and predicted values (residuals) reflect potential IOP effects. Unlike the above regression model, this procedure does not assume that the regression slope for rainfall (B_1) is constant. While formal hypothesis tests are not performed, this simple graphical technique has been used as an exploratory tool to supplement the multiple regression analyses.

Figure 4 demonstrates application of the screening procedure to data for the combined outflows from WCA-3A to Shark Slough (S12X+S333). The utility of basin rainfall as an index of regional hydrologic variability is supported by the fact that the model explains 94%, 82%, and 82% of the variance in the observed outflows, loads, and concentrations, respectively. Results indicate that mean concentration was significantly higher during the IOP period by 1.9 ppb or 22% ($p = 0.02$). The result is confirmed by the fact that the pre-IOP regression vs. rainfall underestimates the observed concentrations in each IOP year. Apparent changes in mean flow (decrease) and load (increase) are not significantly different from zero.

<<< Figure 4

4.0 Screening Results

Screening results are summarized in Table 2. Percentage differences in flow, load, and concentration between the pre-IOP and IOP periods are shown in Figure 5 and mapped in Figures 6-8. Additional details (statistical modeling results, data plots, etc.) are given in the Appendix and posted at http://www.wwwalker.net/iop. Results are discussed by region (WCA_3A inflows, Shark River Slough, Taylor Slough/Eastern Panhandle) below.

<< Table 2
<< Figure 5
<< Figure 6
<< Figure 7
<< Figure 8

4.1 WCA-3A

Apparent changes in WCA-3A inflows and potential factors include:

1. Decreases in G155 flow and load. Flows discharged via G155 into the northwest corner of WCA-3A originate primarily in the C139 Basin. Recent reductions in flow and load can be attributed to diversion of most of the C139 basin runoff to Stormwater Treatment Area 5 (STA-5)

in 2000. Discharges from STA-5 now enter the Rotenberger tract or the Miami Canal north of S8. G155 still receives STA-5 bypass flows and occasional diversions from the Miami Canal via G404.

2. Decreases in S11X flow, load, and concentration. S11A, S11B, & S11C discharge from WCA-2A into northeast WCA-3A. The reduction in flow is possibly related to changes in water management, including reduction in regulatory releases from Lake Okeechobee to the Hillsboro Canal via S2, backpumping of EAA runoff to Lake Okeechobee to raise lake level during 2001 drought, and increased outflows from WCA-1 and WCA-2A to the east. The latter may be related to the IOP component that delivers additional flow from the WCA's to the L31N/C111 basin via canals on the eastern edge of the WCA's. Though not significant, the apparent decrease in concentration (22%, p = 0.21) may be related to reduction in phosphorus loads to WCA-2A when STA-2 started full-scale operation in July 2001 and/or reduction in lake releases to WCA-2A via S2/S7. Comparison of the pre- and post- STA-2 periods (1994-2000) vs. (2001-2003) indicates that there was a significant decrease in S11X concentration (39%, p=0.02).

3. Increases in S140 concentration and load. Flows from the L28 canal and the Western L-28 basin are pumped east into WCA-3A at S140. Apparent increasing trends over the 1994-2003 period are not explained by rainfall or flow. It is unlikely that the trends were related to IOP. They may be related to changes in the drainage basin and/or diversions to the L28 canal from inflows to the northwest corner of WCA-3A.

4. Increases S9 in flow, concentration, and load. Runoff from the C11 West basin is pumped into eastern WCA-3A at S9. A portion of the flow is recycled seepage from adjacent WCA-3A and WCA-3B. Actual flow increases from this basin may have been higher because the data do not reflect flows from the smaller S9A pump station that was activated during the IOP period to handle seepage that was formerly handled by S9. Apparent increasing trends in concentration and loads are not explained by rainfall or flow. It is possible that they are related to urban development in the C11W basin.

5. Small decreases in the WCA-3A total inflow and outflow volumes. Increased inflows from S9 were offset by decreases from S11X and G155. There were small apparent decreases in both total inflow (-11%, p=0.20) and outflow through S12X+S333 (-5%, p=0.62), but these were not

significantly different from zero.

6. <u>No significant change in the total load or the average inflow concentration to WCA-3A</u>. Increases in load at S140 and S9 were offset by decreases in load from G155 and the S11's.

Results indicate that diversions from the WCA's associated with the IOP may have resulted in small changes in the amount and distribution of inflow to WCA-3A. Reductions in flow and load to the northern portion of WCA-3A can be attributed to STA operation. While apparently unrelated to the IOP, increases in load to the central portion of WCA-3A via S140 (71%) and S9 (78%) are of potential water quality concern because these inflows are closest to ENP inflow structures. The percentage of the total load to WCA-3A attributed to these sources increased from 9% in the pre-IOP years to 21% in the IOP years (Table 1).

4.2 Shark River Slough

Apparent changes at ENP Shark River Slough (SRS) inflow structures include:

1. <u>Increases in concentration</u>. The combined flow-weighted mean concentration (S12X+S333) increased by 1.9 ppb or 22%. There was an apparent decrease in flow (-5%) and increase in load (13%), but these changes were not significant ($p = 0.62$ and 0.39, respectively). Concentration increased at individual structures by amounts ranging from 0.7 to 2.8 ppb, or 10 to 40%. The largest increase occurred at S12A and the smallest, at S12C.

2. <u>Shift in WCA-3A outflows from the S12X structures to S333</u>. This shift is a consequence of the diversion of dry season flows away from western Shark Slough through S333 to Northeast Shark Slough and the L31N/C111 basin. The overall pattern is consistent with the IOP strategy, although changes in yearly flows at individual structures were not statistically significant, partially because dry-season flows represent small portions of the total yearly flows.

Increases in phosphorus loads to the central portion of WCA-3A via S140 and S9 (WCA-3A inflow points closest to the Park inflow structures) may have contributed to the apparent increase in concentrations at the S12's and S333. The potential for phosphorus transport from these or other WCA-3A inflows to ENP inflow structures has not been evaluated. Such an evaluation would be complicated by mixtures of canal flow and marsh sheet flow through WCA-3A. Transport of loads from S9 may be facilitated by the L67 levee along the southeastern border of WCA-3A, particularly when WCA-3A is at low stage and a higher fraction of the flow is likely to bypass the WCA-3A marsh.

The WCA-3A regulation schedule was modified under the IOP to allow drawdown of water levels by an additional 0.5 feet between February and mid July, as compared with the pre-IOP schedule (Figure 9). For the following reasons, it is likely that this change also contributed to the phosphorus increases at ENP inflow structures:

1. An inverse relationship between phosphorus concentration and water depth is typically observed at marsh monitoring sites in the Everglades, particularly at enriched sites. Stage dependence is reflected in marsh phosphorus levels specified under the State/Federal Consent Decree for Loxahatchee National Wildlife Refuge (Hoeveler, 1991; SFWMD, 1993). The pattern is partially related to enhancement of phosphorus recycling from vegetation and soils at low water levels.

2. WCA-3A stage and the frequency of releases at low stage increased under the IOP. Daily stage and outflow (S12+S333) are plotted in Figure 10. Periods when flow was released at water levels below Zone E (pre-IOP) are indicated. While such releases occurred at various times throughout the 1994-2003 period, their frequency and magnitude (as a percentage of the total yearly outflow volume) increased after 1999.

3. Periods of WCA-3A drawdown were associated with spikes in outflow concentration and load discharged to Shark River Slough. Monthly mean rainfall, stage, outflow, load, and concentration are shown in Figure 11. Outflow concentrations increased significantly when stage dropped below 9-10 feet. Both S12X and S333 concentrations were elevated during these periods. Spikes in outflow load occurred during periods of rising stage following drawdown, when rainfall and external phosphorus inputs to WCA-3A also increased with the onset of the wet season. The largest loading spike in the IOP period (~3500 kg/month) occurred in August 2001 after the lowest drawdown (~8.5 feet) in June 2001. Most of this load went into Northeast Shark Slough through S333.

4. Monthly flow-weighted mean outflow concentrations are inversely correlated with stage. Correlations between outflow concentration and stage, outflow volume, and rainfall are shown in Figure 12. Lines show pre-IOP regressions. Stage explains a higher percentage of the variance ($r^2 = 0.57$), as compared with flow ($r^2=0.45$) or rainfall ($r^2=0.02$).

5. An inverse relationship between P concentration and WCA-3A stage is evident at many structure and monitoring sites in WCA-3A and ENP Shark Slough (Figures 13 & 14). Concentrations increase when stage drops below stage ~9.5 feet at all outflow sites (S12X, S333, US41-25), flows under the Tamiami Trail into Big Cypress (TAMBR105), interior sites in the central and southern portions of WCA-3A (CA311, CA315), and marsh sites in ENP SRS (NE1, NP201, P33, P35, P36). The pattern is less evident at sites in the northern portion of WCA-3A (CA32-38) possibly because these sites are located at higher elevations and are generally not sampled when the average WCA3A stage is below 9.5 feet.

<< Figure 9
<< Figure 10
<< Figure 11
<< Figure 12
<< Figure 13
<< Figure 14

Low stages are to some extent unavoidable during drought. Figure 15 tests the hypothesis that lower stages under IOP reflect variations in rainfall, as opposed to the change in regulation schedule. Outflow characteristics (flow, load, concentration) and various expressions of WCA-3A water levels are plotted against rainfall. Lines show linear regressions for the pre-IOP years. The increase in average outflow concentration is reflected by the fact that data from the IOP period consistently fall above the pre-IOP regression. A similar pattern is observed for expressions of stage and drawdown (mean stage, frequency below Zone E, percent of yearly flow released below Zone E, and frequency of stage below 9.5 feet). These patterns suggest that lower stages observed under IOP are not explained by variations in rainfall and are at least partially related to the change in regulation schedule. Hydrologic analyses (Ahn, 2003) indicate that significant changes in dry-season stage occurred at several marsh sites in WCA-3A and ENP SRS following implementation of IOP, allowing for variations in rainfall.

Increases in SRS inflow P concentrations under IOP are entirely explained by the change in regulation schedule, however. Outflow concentrations are plotted against rainfall, stage, flow, and other measures of WCA-3A drawdown in Figure 16. Lines show pre-IOP regressions. The IOP concentrations are consistently above the pre-IOP regression lines in all cases except for that based upon the percentage of flow released below Zone E. While strongly correlated with the reduction in stage, shifts in the distribution of flow away from the S12’s to S333 is another operational change that may have increased outflow concentrations by increasing the ratio of WCA-3A marsh sheet flow to canal flow in the combined outflows. This factor is somewhat discounted, however, because (1) the concentration increase was greater at S12A than at the other structures (40% vs. 10-20%, Table 2), (2) the amount of flow shifted was a small fraction of the annual flow volume; and (3), the fraction of yearly flow volume discharged through S333 was not significantly higher in the IOP years as compared with the pre-IOP years at a given rainfall (Figure 15). Further analyses, including monthly time series modeling, indicate that the concentration increases are not entirely explained by WCA-3A drawdown. Outflow concentrations also tend to exceed pre-IOP regressions in months with high stage (>10.5 ft) or rainfall (> 3 inches/month) (Figure 12). Concentrations during these periods have a large impact on the yearly flow-weighted means.

<<Figure 15
<< Figure 16

No significant changes in average SRS inflow concentrations after IOP implementation were found when the above analysis was repeated using a 1988-1999 (vs. 1994-1999) baseline period. While the longer baseline is desirable because it includes dry years (Figure 2), interpretation of the results with respect to IOP impacts is difficult because the variety of operational schemes utilized during this extended period and possible shifts in the baseline attributed BMP implementation in the EAA during the mid 1990’s.

In summary, potential mechanisms responsible for the observed ~20% increase in WCA-3A outflow concentrations to Shark River Slough between 1994-1999 and 2000-2003 include:

1. Increases in external phosphorus loads to the central portion of WCA-3A via S9 and S140;
2. Increases in phosphorus recycling from marsh soils and vegetation promoted by WCA-3A drawdown under the IOP;
3. Increase in the proportion of flow through S333 vs. S12X.
4. Enhancement of phosphorus transport from external sources through WCA-3A as a consequence of drawdown and its associated hydraulic effects:
    a. Decreases in WCA-3A area, storage volume, and water residence time required for assimilation of external loads by the WCA-3A marsh;
    b. Increases in the proportion of canal flow vs. marsh sheet flow at low stage, particularly down the Miami Canal and along L67.

The relative importance of these mechanisms is not understood. The fourth mechanism suggests a possible interaction between the apparent effect of IOP (WCA-3A drawdown) and transport of external loads through WCA3A. Development of an understanding of these mechanisms and interactions is recommended to support future management of the system to attain hydrologic and water quality goals.

4.3 Taylor Slough/Eastern Panhandle

Apparent differences between the 1994-1999 and 2000-2003 periods in ENP's Taylor Slough and Eastern Panhandle basins include:

1. Increase in flow delivered to the L31N canal from the North (S334 + S335 – S336). This is consistent with the IOP strategy to divert flows away from western Shark Slough and the WCA's to the L31N/C111 basins. Concentrations were not measured at S335, so that impacts on load and concentration entering the L31N are based upon concentration measurements at S333.

2. No change in G211 or S331 flow. Most of the increased flow delivered to L31N through S334 and S335 was diverted east through S338 (Figure 3). This indicates that there was no net increase in flow delivered to the southern L31N/C111 canals from the WCA's under IOP. Phosphorus data are insufficient to test for changes in load or concentration at G211 or S331, so results are not reported along with those for other structures.

3. Increase in S174+S332D flow. These are discharges from L31N west to L31W and the S332D detention/Frog Pond area. The increase reflects operation of the S332D pump station starting in 1999. The S332B and S332C pump stations also diverted additional flows to detention areas west of L31N (not shown because of there was no baseline). These do not necessarily represent increases in flow delivered to ENP because of seepage return from the detention areas to the L31N/C111 canals.

4. Decrease in S332+S175 flow. These direct discharges to Taylor Slough from the L31W were essentially stopped in 2000 under the plan to modify deliveries to the Slough.

5. Decrease in S176 flow. This is consistent with diversions from L31N to the west via S332D and S332B.

6. No change in S177 flow. The flow deficit at S176 did not occur further downstream at S177. This may be attributed to seepage return from the S332D detention area and/or increased groundwater inflows from the east attributed to operation of lower L31N canal levels under IOP.

7. No change in S18C flow or net delivery to the ENP eastern panhandle (S18C-S197). Despite increased pumping out of the L31N into the buffer zone via S332D and S332B, there was no net decrease in flow at S18C. This suggests that most of the flow pumped west into the detention areas seeped back into the L31N/C111 canals above S18C. Increased seepage inflows from the east and west as a consequence of lower canal operating stages under IOP may have also offset the flows pumped out of the L31N into the detention areas.

Screening of the L31N/C111 data identified no significant changes in phosphorus concentration after IOP implementation. Any changes that may have occurred over the 1994-2003 period could not be detected in the presence of background variability in the data. There are some signs of improvement in the basin, but these cannot be confirmed statistically or ascribed specifically to IOP. With the exception of S177, there were apparent decreases in concentrations after IOP, but these changes (2% to 23%) were not statistically significant. There were also apparent declining trends at ENP marsh sites P37 and EP over the 1994-2003 period (Figure 13), but confirmation of these trends is difficult because of the low concentration range and decrease in phosphorus detection limit from 4 to 2 ppb in 2002, which may affect comparability with data from previous years. Independent analyses of SFWMD data by the Corps of Engineers (2003) identified decreasing trends at S176 and S18C between 1983 and 2002. Given the length of the period and data limitations discussed below, however, these apparent trends cannot be ascribed specifically to the IOP.

The following factors and data limitations, most of which are less important in or absent from the Shark River Slough data, contribute to variability in the data from this basin and reduce probabilities of detecting changes. The recent data may not adequately reflect long-term water quality conditions likely to result from continuation of the IOP, particularly with future evolution of the C111 project and potential urban development in the region. Factors include:

1. There is greater year-to-year variation in flow-weighted-mean concentration at L31N/C111 structures (CV = 0.25 – 0.45), as compared with Shark River Slough structures (CV = 0.15 – 0.25). This is partially attributed to lower analytical precision in the lower concentration range.

Greater variation decreases the probability of detecting change in a dataset of fixed length (Snedecor & Cochran, 1989).

2. Adjustments for rainfall generally removed less variance from data at sites in this basin, as compared with sites in SRS and WCA-3A. This may reflect the fact that hydrologic variability in the system is controlled more by seepage, canal stages, and local inflows, as opposed to WCA rainfall. Screening results did not change significantly using rainfall measured at S18C instead of the WCA/EAA basin average.

3. The 2000-2003 IOP period did not include wet years, which would be critical to evaluating long-term water quality impacts of operating the system (via the S332B/C/D pumps and lower canal elevations) to provide flood control for areas east of the canals.

4. Similarly, wet year data are needed to assess critical conditions and long-term-average loads at S18C, which are influenced by direct agricultural runoff via the C111E canal via S178. While flow data are insufficient to evaluate loading at S178, geometric mean concentrations at this site increased from 21 ppb in the 1994-1999 to 32 ppb in 2000-2003. Unlike most other sites in the ENP region, concentrations at S18C tend to increase at high flows, a pattern typical of sites influenced by runoff (e.g., S9 or S8). For example, monthly flow-weighted concentrations at the S12's generally decrease from ~15 ppb at low flows to ~6 ppb at high flows, whereas concentrations at S18C increase from ~6 ppb at low flows to ~20 ppb at high flows. Canal water budgets indicate that under the dry-average rainfall conditions typical of 2000-2003, flow and concentrations at S18C are likely to be dominated by seepage from ENP and the L31N/C111 buffer cells, as opposed to watershed runoff.

5. With the exception of S332D, the screening analysis is based exclusively upon biweekly grab samples. This sampling strategy is generally inadequate for detecting infrequent spikes in concentration and loading associated with runoff events and flood-control operations. Such spikes may account for a large fraction of the total annual load at a given site. Grab sampling may be adequate to measure loads at the S12's, but continuous flow-weighted composite sampling is needed to measure loads at S18C and other sites in the basin possibly affected by runoff events or flood control operations. Figure 17 compares SFWMD grab and weekly composite samples at S332D and S18C. Composites are significantly higher than grabs in some periods, particularly when flows are high. Because S18C composite sampling was not initiated

until 2003, the above screening analysis was based exclusively upon grab samples at that location. While it is possible that some of the differences between grabs and composites can be attributed to initial “shake-down” of the automatic sampling devices or other artifacts, there is a significant risk that grab samples under-estimate flow-weighted-mean concentrations and loads at these and other structures in the basin.

6. The initial phases of the C111 buffer project (including S332B, S332C, S332D, and their associated detention areas, and other components) were not in full scale operation in the 2000-2003 IOP period analyzed. Local inputs to the L31N/C111 canals are diluted by seepage losses from the Park (Walker, 1997). An increase in concentration would be expected when the buffer project is in full operation and seepage losses are reduced, particularly if the system is operated to provide additional flood control for developed areas east of the canals. Occasional phosphorus spikes (20 – 90 ppb vs. baseline < 10 ppb) in the C102 and C103 data from 2001-2003 (Anamar, Inc. et al, 2003) provide evidence of inputs from eastern developed areas that are inadequately characterized by grab sampling. Contributions from these areas may increase with future land development and/or system operation to provide additional flood protection.

<< Figure 17

Historical data do not provide evidence of water quality deterioration in the L31N/C111 basin as a consequence of IOP and other changes in system operation that occurred in the 2000-2003 period. Given data limitations and difficulties associated with forecasting effects of C111 project completion, changes in operation, and changes in land use, future management should be guided by intensive monitoring, data analysis, modeling, and research to develop a better understanding of mechanisms controlling hydrology and water quality.

Existing data do not support reliance on the C111 buffer cells for water quality protection. Potential mechanisms for water quality enhancement in the cells include (1) biological uptake from surface waters; (2) particle settling from surface waters; and (3) filtration/adsorption from seepage flows returning to the L31N/C111 canals or entering the adjacent ENP marsh. Although a substantial monitoring effort has been undertaken by the Corps of Engineers (Anamar, Inc, 2003) and recently by SFWMD (2002), currently available water quality and hydrologic data are insufficient to evaluate the water quality dynamics of the detention areas and to quantify flows and concentrations in surface and groundwater outflows from the detention basins. Preliminary application of the Dynamic Model for Stormwater

Treatment Areas (DMSTA, Walker & Kadlec, 2002) to data from 1999-2002 indicates that 25% of the inflow phosphorus load was discharged as surface overflow,70% was lost to seepage, and 5% was retained in the system. Owing to high infiltration rates and high hydraulic loadings during pumping events, water residence time (< 1 day) was insufficient to allow significant biological uptake of inflowing phosphorus loads. The direction and fate of phosphorus transport in seepage and effects of antecedent soil phosphorus are unknown.

Phosphorus concentrations measured in the vicinity of the outflow weir from the S332B detention basin were generally lower than inflow concentrations during its infrequent overflow events in 2001-2003 (Figure 18). It is possible that these reductions reflect physical mechanisms (settling, adsorption), as opposed to biological uptake (COE, 2003). Basin concentrations were much higher (10 – 300 ppb) during periods without overflow, which accounted for most of the time and seepage losses. Depending upon seepage direction and phosphorus transformations in groundwater, seepage outflows from this basin and others in the C111 project may impact adjacent ENP marshes. Unless specific and predictable removal mechanisms are identified, the detention basins should not be relied upon to provide significant water quality treatment. Given the uncertainties and risks, prudent operation of the system would minimize inputs to the Park in forms of seepage or direct overflow.

<< Figure 18

5.0 Compliance with Consent Decree Inflow P Limits

The State/Federal Consent Decree (Hoeveler,1991) sets yearly limits on inflow phosphorus concentrations to Shark River Slough (effective October 2003) and to the Taylor Slough/Eastern Panhandle basins (effective December 2006). This section discusses 1994-2003 data in relation to the limits for each basin (Figures 19 and 20, respectively). While the limits were not effective during this period, the data provide a basis for assessing current status and potential impacts of IOP and other factors that may influence future compliance. For consistency with the above analyses, the procedures used in computing basin flow-weighted-mean concentrations differ slightly from those that will be used in compliance determination with respect to computation of basin totals (combining annual flows and loads across structures vs. combining flows and loads on dates when concentrations were measured) and water year definition (May-June vs. October-September). Conclusions are not sensitive to these differences, however.

<< Figure 19

<< Figure 20

Figure 19 shows yearly SRS inflow concentrations in relation to interim limits computed from basin flow. The flow dependence reflects a negative correlation between concentration and flow in the 1978-1990 data used to derive the limits (Walker 1999b, 2002). The flow adjustment is analogous to the rainfall adjustment used in the above analysis. The objective of establishing the limits was to restore 1978-1979 water quality conditions. Consistent with the above results, there was an apparent increase in concentration (2.0 ± 0.8 ppb) at a given flow after IOP implementation. In 1994-1999, concentrations varied between the target and limit, which reflect the 50th and 90th percentiles of 1978-1979 concentrations. After 1999, concentrations were consistently close to the limit. The apparent increases are independent of whether the hydrologic adjustment is based upon flow or rainfall, as further demonstrated in Figure 16. As discussed above, the increases may be related to changes in the WCA-3A regulation schedule under IOP and/or trends in phosphorus loads to WCA-3A from specific basins.

Figure 20 shows yearly inflow concentrations for the Taylor Slough/Eastern Panhandle basins in relation to the 11 ppb limit. The limit is fixed because there was no apparent correlation between flow and concentration in the 1983-1990 baseline data. Concentrations generally fluctuated between the target and limit lines in 1994-2003, with no apparent change after IOP implementation. The 11 ppb limit was exceeded in one year (1995), which also had the highest rainfall and the highest concentration at S18C. While recent data suggest an optimistic compliance forecast, concentrations in 2000-2003 were not representative of wet years or future conditions with the C111 buffer project in full operation.

Changes in water delivery to Taylor Slough under IOP have introduced new complexities into the tracking of compliance in this basin. Basin flow-weighted concentrations were originally computed using grab sample and flow data from structures discharging directly into the Park (S18C, S175, and S332). Since deliveries through S332 and S175 were stopped in 2000, compliance has been tracked using data from S18C, S174, and S332D (SFWMD, 2003). The S174 and S332D flows enter the L31W and S332D detention areas and do not enter the Park directly. This procedure is used because the monitoring systems for tracking direct inflows to the Park in this region via overflow from L31W, overflow from detention areas, and seepage are not in place. New discharges through S332B and S332C, which may increase phosphorus loads to the Park via overflow and/or seepage from the detention areas, are ignored altogether in tracking compliance. Phosphorus initially stored in the soils of the detention areas may be stripped and transported into the adjacent marsh via overflows or seepage.

With operation of the new pump stations (S332B, C, D) and lowering of L31N/C111 canal stages to provide increased flood control for adjacent developed areas, the current procedure of utilizing grab samples exclusively in tracking compliance may not provide an adequate estimation of ENP inflow concentrations or loads under current conditions. As illustrated in Figure 20, flow weighted means for S332D, S18C, and the basin whole are higher when composite samples are utilized in the calculations. These are significant issues that need to be resolved in tracking future compliance, supported by data from an expanded monitoring program recently implemented by SFWMD (2002).

6.0 Operational Recommendations

Based upon the above results, the following recommendations are made for operating the system to minimize water quality impacts with respect to phosphorus:

1. While the apparent increase in phosphorus concentrations in Shark River Slough inflows after IOP implementation may be attributed to a combination of factors, there is sufficient evidence linking the increase to the change in WA-3A regulation schedule to recommend modification of the schedule to avoid drawdown of water levels below Zone E, particularly to stages < 9.5 feet.

2. The historical data do not provide evidence of water quality deterioration in the L31N/C111 basin as a consequence of IOP and other changes in system operation that occurred in the 2000-2003 period. Given the historical data limitations and difficulties associated with forecasting effects of C111 project construction, changes in operation, and changes in land use, future management should be guided by intensive monitoring, data analysis, modeling, and research.

3. Available data do not support reliance on the L31N/C111 detention areas for water quality protection. It is recommended that the areas be designed and operated to minimize inputs to the Park in the form of seepage or direct overflow.

4. There is evidence of water quality impact at S18C by runoff from the C111E sub-basin, particularly in wet years. It is recommended that plans to provide future treatment of that runoff be reviewed and possibly accelerated.

7.0 Monitoring and Assessment Recommendations

The following monitoring and assessment recommendations are made to improve understanding of factors controlling water quality and support future management decisions:

1. Further analysis and modeling of existing data from WCA-3A to evaluate factors contributing to recent increases in phosphorus concentrations at the S12's and S333, including but not limited to changes in regulation schedule and apparent increases in inflow phosphorus loads from S140 and S9.

2. Assessment of factors responsible for recent increases in phosphorus concentration at S12A, which were larger than those observed at other Shark River Slough inflow structures.

3. An increased emphasis on composite sampling to track phosphorus concentrations and loads at monitoring sites in the L31N/C111 region, including sites on the mainstem canals, sites on eastern canals (C102, C103, C113, C11E), pump stations, and buffer/detention area overflow points.

4. Intensified monitoring of the L31N/C111 detention areas to support development of accurate water and phosphorus budgets, to assess the transport and fate of phosphorus in surface and groundwater flows, and to support modeling of phosphorus dynamics.

5. Development and periodic updating of regional-average rainfall datasets for ENP, the WCA's, and contributing watersheds to support evaluation of future water quality and hydrologic trends in the context of background climatologic variations using methodologies similar to that employed in this report.

6. Continued refinement of the data and computation algorithms for tracking compliance with Consent Decree limits in the L31N/C111 basin. These refinements should consider changes in flow distribution and operation that influence phosphorus transport to ENP marshes in via surface flows and seepage, as well as the potential need for composite sampling to measure phosphorus fluxes at pump stations and other sites with highly dynamic flows that were not characteristic of

the baseline period used to derive the limits.

7. Routine measurement of phosphorus concentrations at S335 to track phosphorus transport into the L31N from the North.

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List of Tables

List of Figures

Table 1. Observed Means by Structure and Time Period. Conc = arithmetic mean of yearly flow-weighted means concentrations. FWC = mean load / mean flow for each time period.

	pre-IOP (1994-1999) Means				IOP (2000-2003) Means				
Structure(s)	Flow kac-ft/yr	Load kg/yr	Conc ppb	FWC ppb	Flow kac-ft/yr	Load kg/yr	Conc ppb	FWC ppb	Description
WCA-3A Inflows									
G155	112	25380	188	184	37	9585	191	208	G155 Outflow to NW WCA-3A
S8+G404	374	44183	94	96	282	32126	85	92	Outflow from Miami Canal to NW WCA-3A
S150	50	3469	59	56	44	2876	52	54	S150 Outflow to NE WCA-3A
S190	89	13075	113	120	77	9722	109	102	S190 Discharge to Westerm WCA-3A
S140	134	6464	40	39	119	10119	74	69	S140 Discharge to Western WCA-3A
S11X	634	19828	28	25	353	10582	22	24	WCA-2A Outflow to WCA-3A: S11A+B+C
S9	243	4225	14	14	255	6774	22	22	Discharge from C11W Basin to WCA-3A
WCA-3A IN	1635	116624	57	58	1167	81784	55	57	Total Inflow to WCA-3A
ENP Shark River Slough									
S12A	183	1413	7	6	103	1263	10	10	S12A from WCA-3A to ENP Shark Slough
S12B	155	1211	6	6	109	1027	8	8	S12B from WCA-3A to ENP Shark Slough
S12C	315	2723	7	7	209	2062	9	8	S12C from WCA-3A to ENP Shark Slough
S12D	396	4054	9	8	240	3147	11	11	S12D from WCA-3A to ENP Shark Slough
S12X	1050	9401	8	7	661	7499	10	9	WCA-3A Outflow to ENP Shark Slough: S12ABCD
S333	165	2321	11	11	186	3129	14	14	S333 from WCA-3A to NESRS & S334
S12X+S333	1215	11722	8	8	847	10628	11	10	Shark River Slough Total: S12X + S333
NESRS	155	2099	11	11	144	2559	14	14	Net Inflow to Northeast Shark Slough: S333-S334
SRS_ENP	1205	11500	8	8	804	10058	11	10	ENP Shark Slough Total = S12X + NESRS
Taylor Slough / Eastern Panhandle									
L31N_IN	60	1039	12	14	139	2232	13	13	Net Inflow to L31N from North: S334+S335-S336
S174+S332D	91	1039	9	9	133	1558	9	9	Outflow from L31N to L31W/ S332D Detention Area
S332+S175	219	1982	7	7	75	726	7	8	L31-W Direct Outflow to Taylor Slough
S176	92	1125	10	10	56	615	8	9	S176 on C111 Canal
S177	137	1147	7	7	127	1643	10	10	S177 on C111 Canal
S18C	200	2871	11	12	166	1541	7	8	S18C on C111 Canal
S18C-S197	165	2129	10	10	142	1254	7	7	Inflow to ENP Panhandle from C111: S18C - S197

Table 2. Results of Screening Analysis. pre-IOP = 1994-1999 mean,. Increase = IOP (2000-2003) mean – pre-IOP mean. % Incr = Increase as percent of pre-IOP mean. p = significance level, two-tailed test (* p < .15, ** p < .05). Values adjusted to average rainfall. Structures are defined in Table 1.

	Flow (kac-ft/yr)					Total P Load (kg/yr)					Mean Concentration (ppb)				
Structure	pre-IOP	Increase	% Incr	p		pre-IOP	Increase	% Incr	p		pre-IOP	Increase	% Incr	p	
WCA-3A Inflows															
S150	52	-11	-23%	0.48		3467	-588	-17%	0.63		56.6	-1.3	-2%	0.90	
S140	124	12	9%	0.50		6034	4730	78%	0.02	**	42.5	28.1	66%	0.06	*
G155	102	-50	-61%	0.03	**	22696	-9085	-40%	0.07	*	183.9	14.1	8%	0.77	
S190	80	11	13%	0.57		11647	217	2%	0.96		112.7	-3.6	-3%	0.86	
S8+G404	347	-23	-7%	0.69		39795	-1086	-3%	0.91		91.9	-3.5	-4%	0.83	
S11X	574	-130	-25%	0.12	*	18443	-5784	-31%	0.02	**	27.9	-6.0	-22%	0.21	
S9	235	32	13%	0.11	*	4091	2885	71%	0.01	**	14.3	7.4	52%	0.03	**
WCA-3A IN	1512	-160	-11%	0.20		106173	-8712	-8%	0.60		56.3	-0.3	-1%	0.97	
ENP Shark River Slough															
S12A	156	-11	-7%	0.78		1190	406	34%	0.24		7.0	2.8	40%	0.01	**
S12B	134	7	5%	0.81		1049	221	21%	0.47		6.6	1.1	17%	0.19	
S12C	281	-21	-8%	0.56		2467	-21	-1%	0.94		7.6	0.7	10%	0.35	
S12D	354	-50	-15%	0.25		3685	17	0%	0.98		9.0	1.8	20%	0.06	*
S12X	925	-76	-8%	0.54		8391	623	7%	0.63		7.9	1.5	19%	0.08	*
S333	166	20	11%	0.72		2345	748	32%	0.43		11.3	2.3	20%	0.02	**
S12X+S333	1090	-56	-5%	0.62		10736	1371	13%	0.39		8.6	1.9	22%	0.02	**
NESRS	157	-15	-10%	0.77		2127	392	18%	0.67		10.8	3.4	31%	0.01	**
SRS_ENP	1081	-91	-9%	0.46		10517	1015	10%	0.54		8.4	2.0	24%	0.02	**
ENP Taylor Slough/Eastern Panhandle															
L31N_IN	63	72	79%	0.01	**	1133	959	85%	0.05	*	13.1	-0.9	-7%	0.71	
S174+S332D	87	51	48%	0.04	**	1027	548	53%	0.31		9.1	-0.2	-2%	0.93	
S332+S175	203	-104	-64%	0.12	*	1858	-947	-51%	0.26		7.2	-0.6	-8%	0.68	
S176	89	-30	-39%	0.11	*	1125	-511	-45%	0.32		9.8	-1.7	-18%	0.58	
S177	131	4	3%	0.86		1140	513	45%	0.25		7.2	2.6	36%	0.20	
S18C	190	-10	-5%	0.69		2616	-691	-26%	0.46		10.5	-2.4	-23%	0.39	
S18C-S197	158	-6	-4%	0.84		1958	-447	-23%	0.60		9.4	-1.8	-20%	0.47	

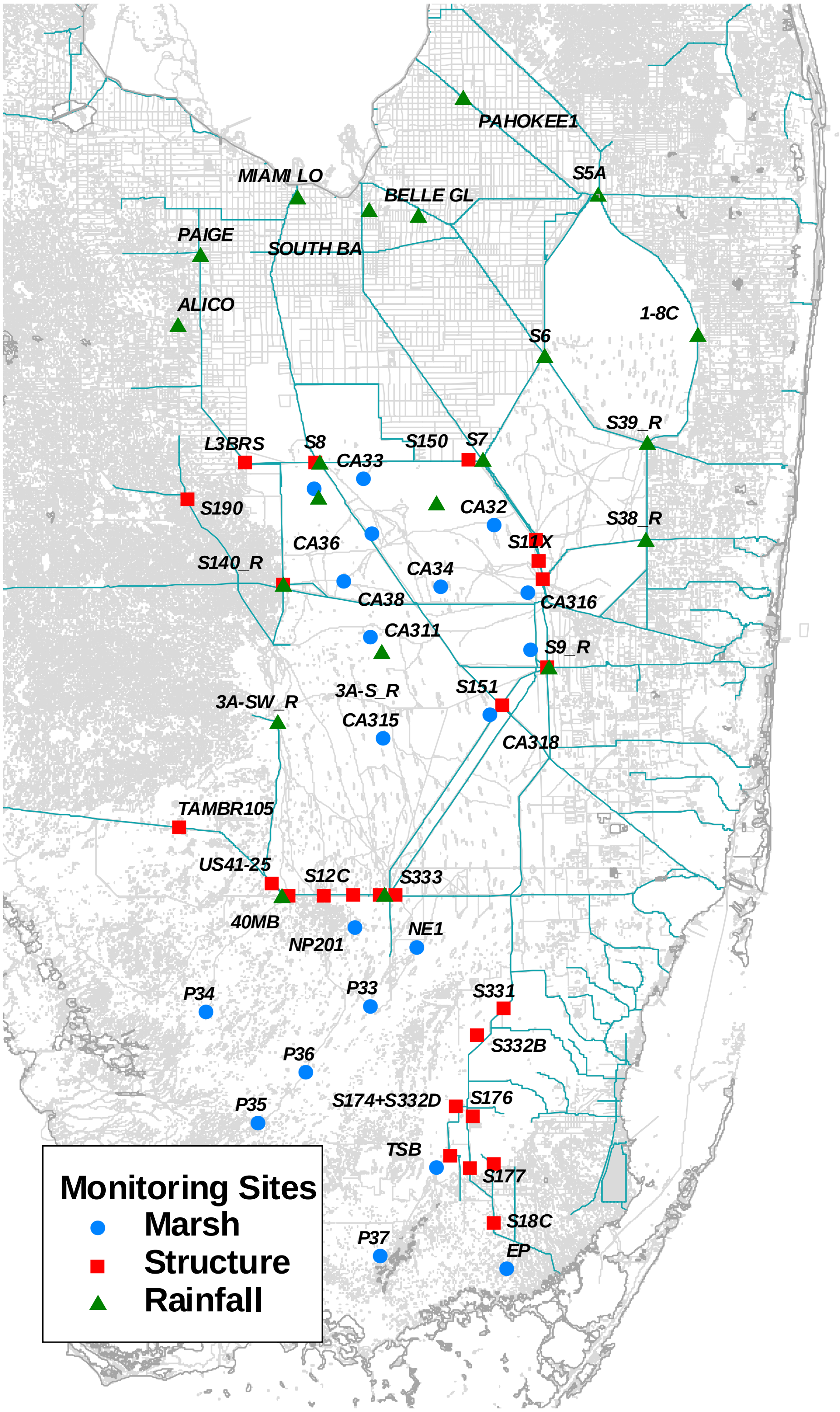


Figure 1. Monitoring Sites.

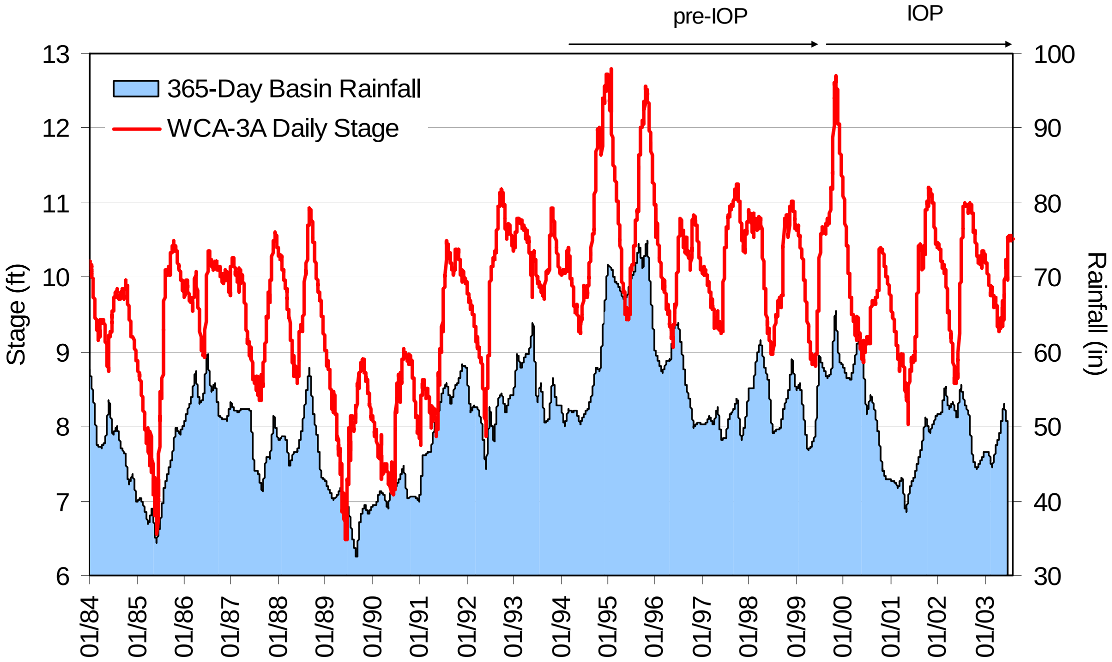


Figure 2. WCA-3A stage and rainfall. Stage is average of 3 stations (Sites 63, 64, 65). Rainfall is a spatial average of sites identified in Figure 1. Arrows show pre-IOP (June 1993- May 1999) and IOP periods (June 1999 – May 2003) selected for the analysis.

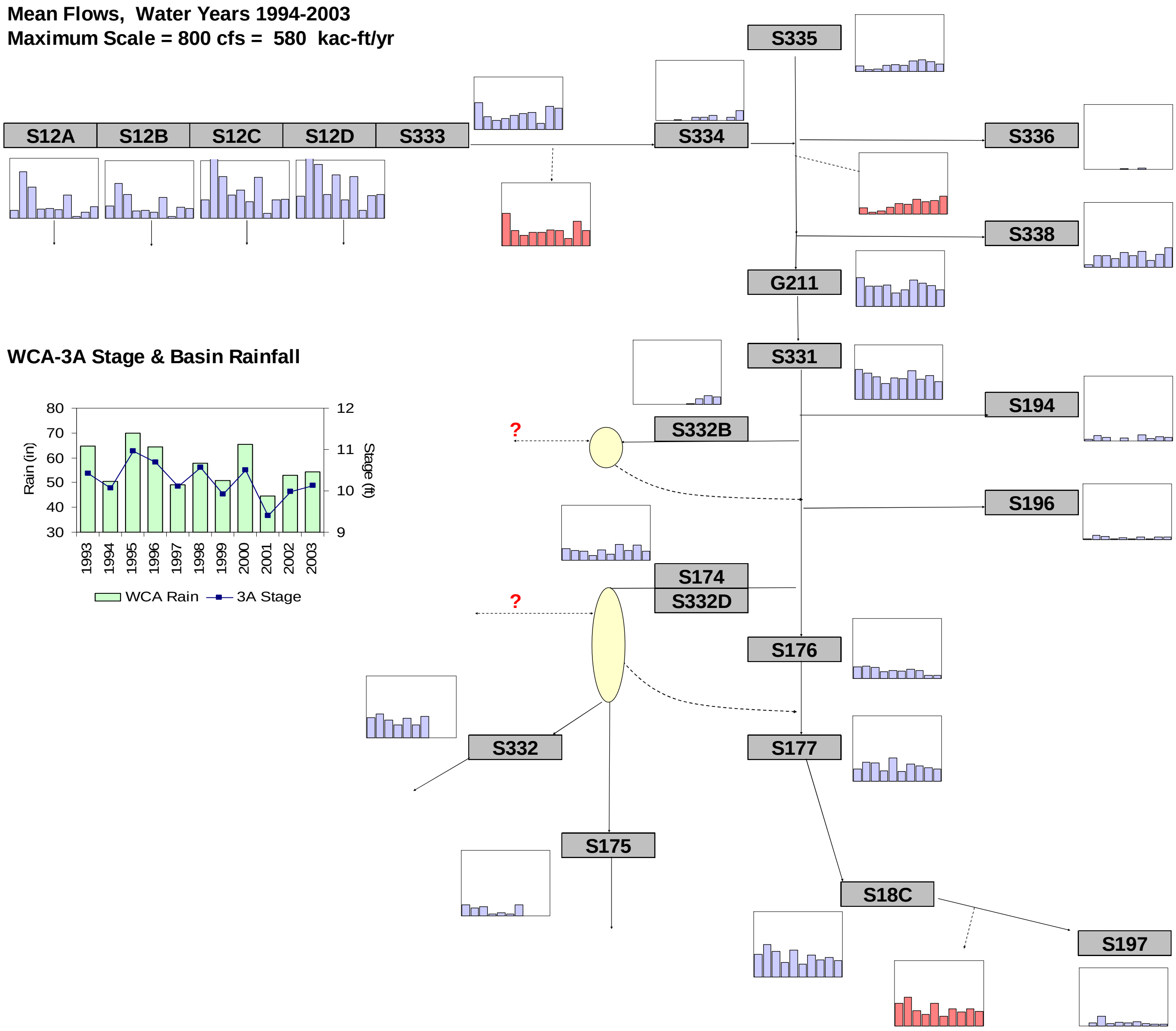
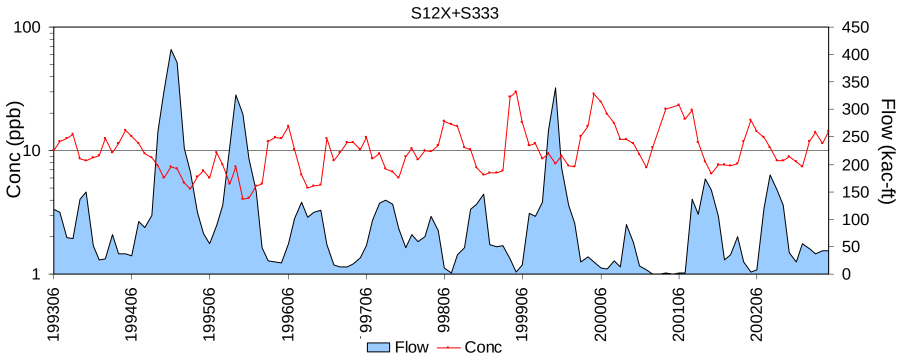
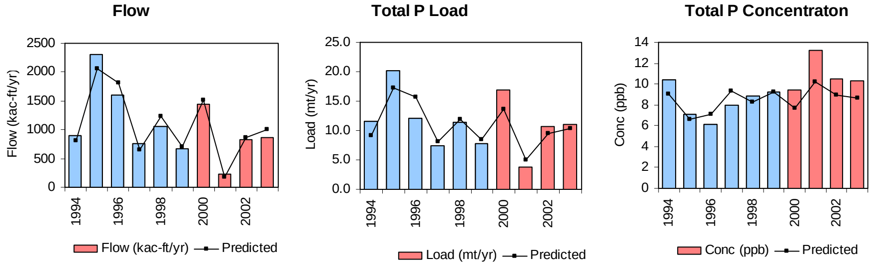


Figure 3. Spatial and Temporal Distribution of Flow. Water Years 1994-2003. Scale maximum = 800 cfs = 580 kac-ft/yr for each structure. Values in red are computed by difference from measured flows at other structures.

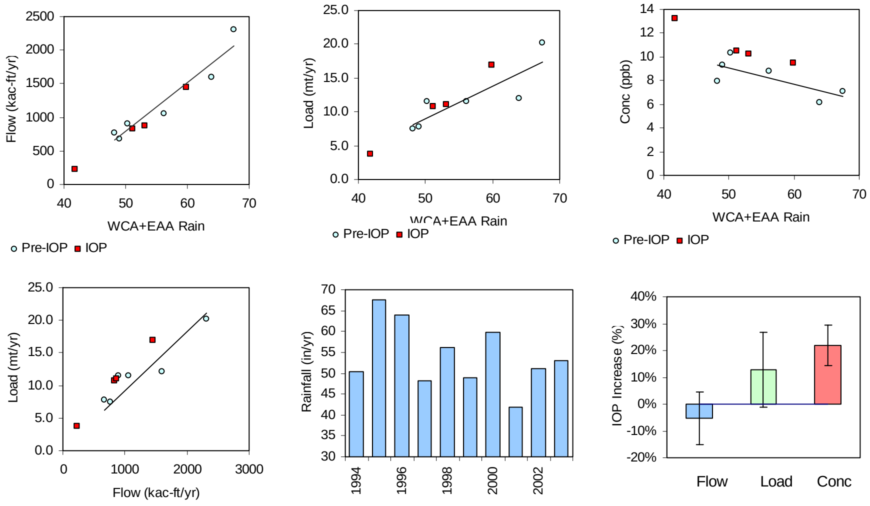
Observed Monthly Flows & Flow-Weighted Mean Concentrations



Water Year Time Series, Lines = Regressions vs. Rainfall for pre-IOP Period



Pre-IOP Regressions:



June-May, 1994-200:

					Rainfall Adjusted Values				Observed Values			
		Water Year			Flow	Load	Conc	FWConc	Flow	Load	Conc	FWConc
Period	Count	First	Last	Rain	kac-ft/yr	kg/yr	ppb	ppb	kac-ft/yr	kg/yr	ppb	ppb
All	10	1994	2003	54.1	1068	11285	9.3	8.6	1068	11285	9.3	8.6
Pre-IOP	6	1994	1999	55.9	1090	10736	8.6	8.0	1215	11722	8.3	7.8
IOP	4	2000	2003	51.5	1034	12107	10.4	9.5	847	10628	10.8	10.2
Increase				-4.4	-56	1371	1.9	1.5	-369	-1094	2.6	2.4
% Increase in Mean				-8%	-5%	13%	22%	19%	-35%	-9%	31%	30%
% Standard Error					10%	14%	7%					
Significance					0.31	0.20	0.01					
Regression R^2					0.94	0.82	0.82					

Model : $Y = B_0 + B_1 \text{ Rain} + B_2 \text{ IOP}$, IOP = 0 or 1

Figure 4. Analysis of ENP Shark River Slough inflow data. Combined inflow = S12X + S333. Example of analysis performed for each structure. Results for other structures are posted at http://www.wwwalker.net/iop

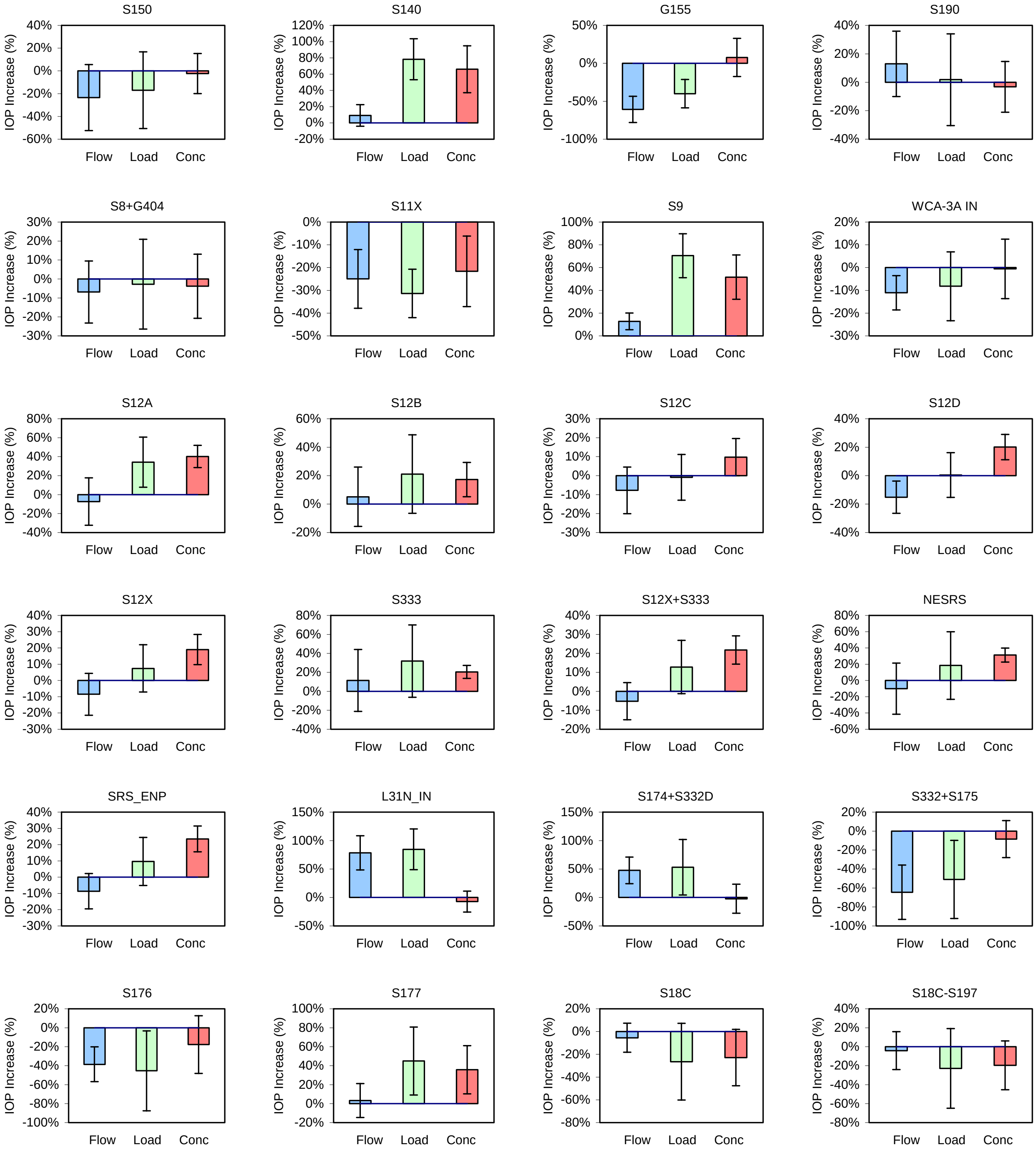


Figure 5. Changes in flow, phosphorus load, and concentration. Increases (IOP mean – pre-IOP mean) as a percent of the pre-IOP mean. Error bars are ± 1 standard error.

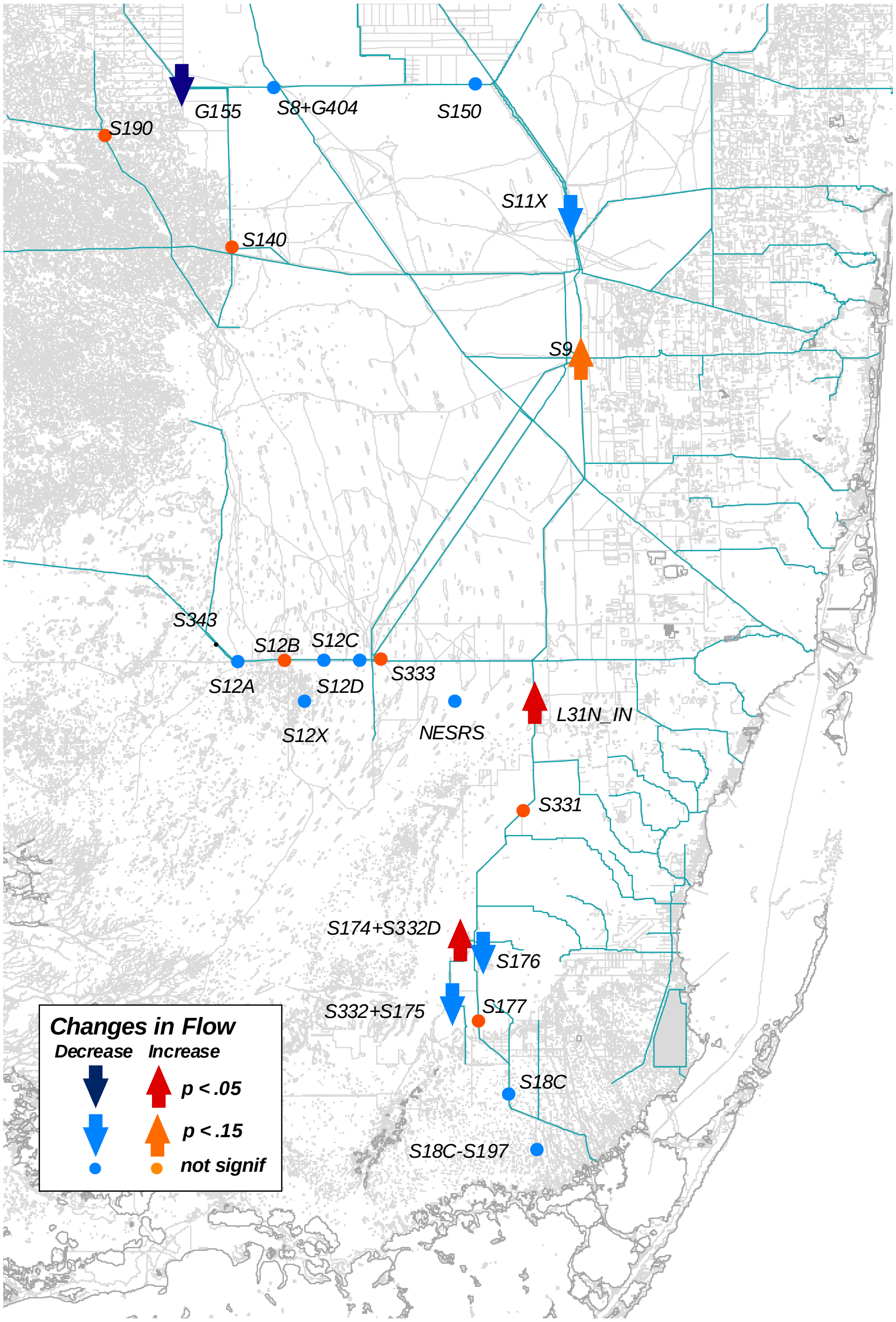


Figure 6. Map of changes in flow. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red p<0.05, orange p <0.15). Down arrow = significant decrease (dark blue p < .05, light blue p < 0.15). Orange circle = increase, not statistically significant (p > 0.15). Blue circle = decrease, not significant (p > 0.15). p/2 estimates the probability that the actual change was in the opposite direction from that indicated.

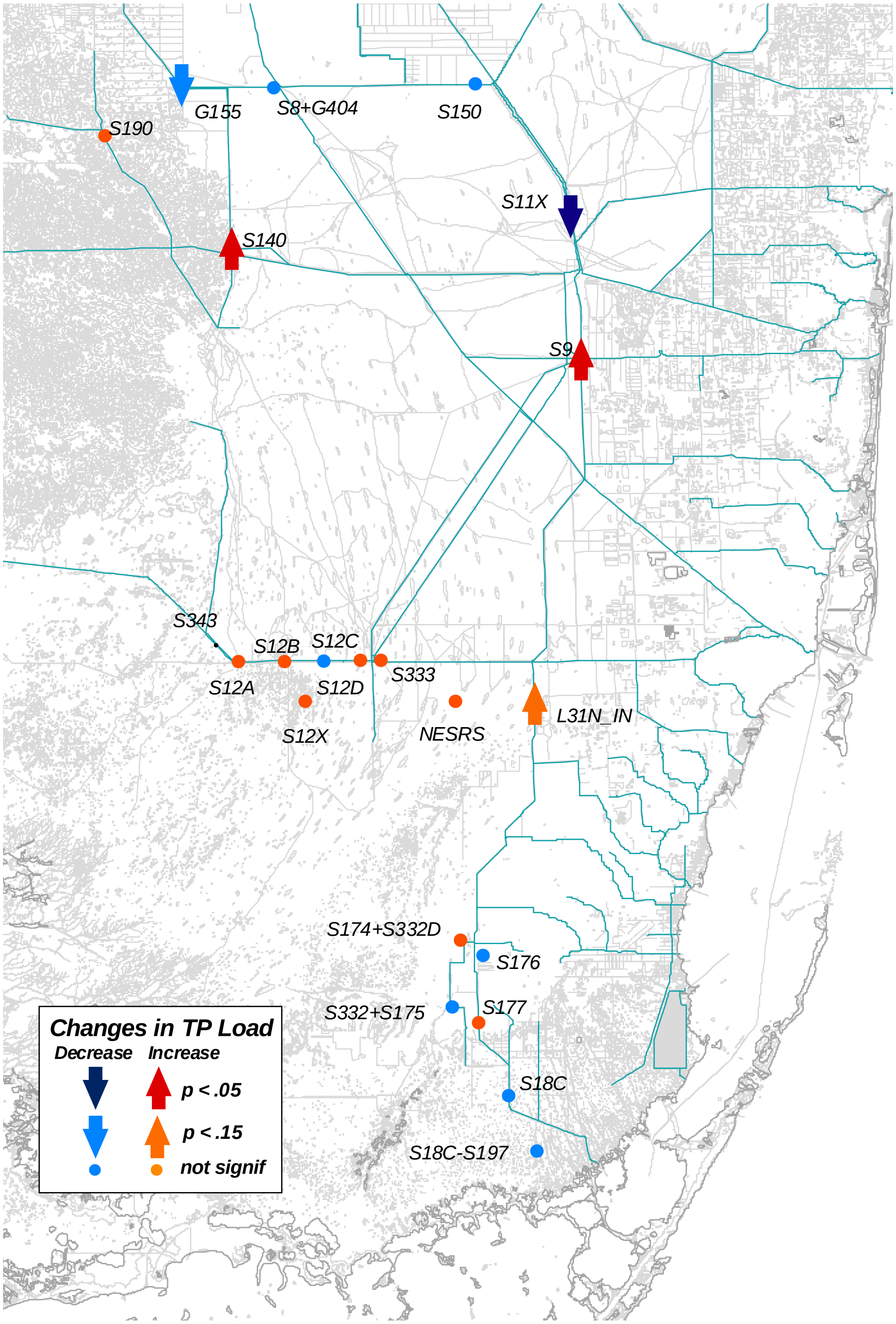


Figure 7. Map of changes in phosphorus load. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red p<0.05, orange p <0.15). Down arrow = significant decrease (dark blue p < .05, light blue p < 0.15). Orange circle = increase, not statistically significant (p > 0.15). Blue circle = decrease, not significant (p > 0.15). p/2 estimates the probability that the actual change was in the opposite direction from that indicated.

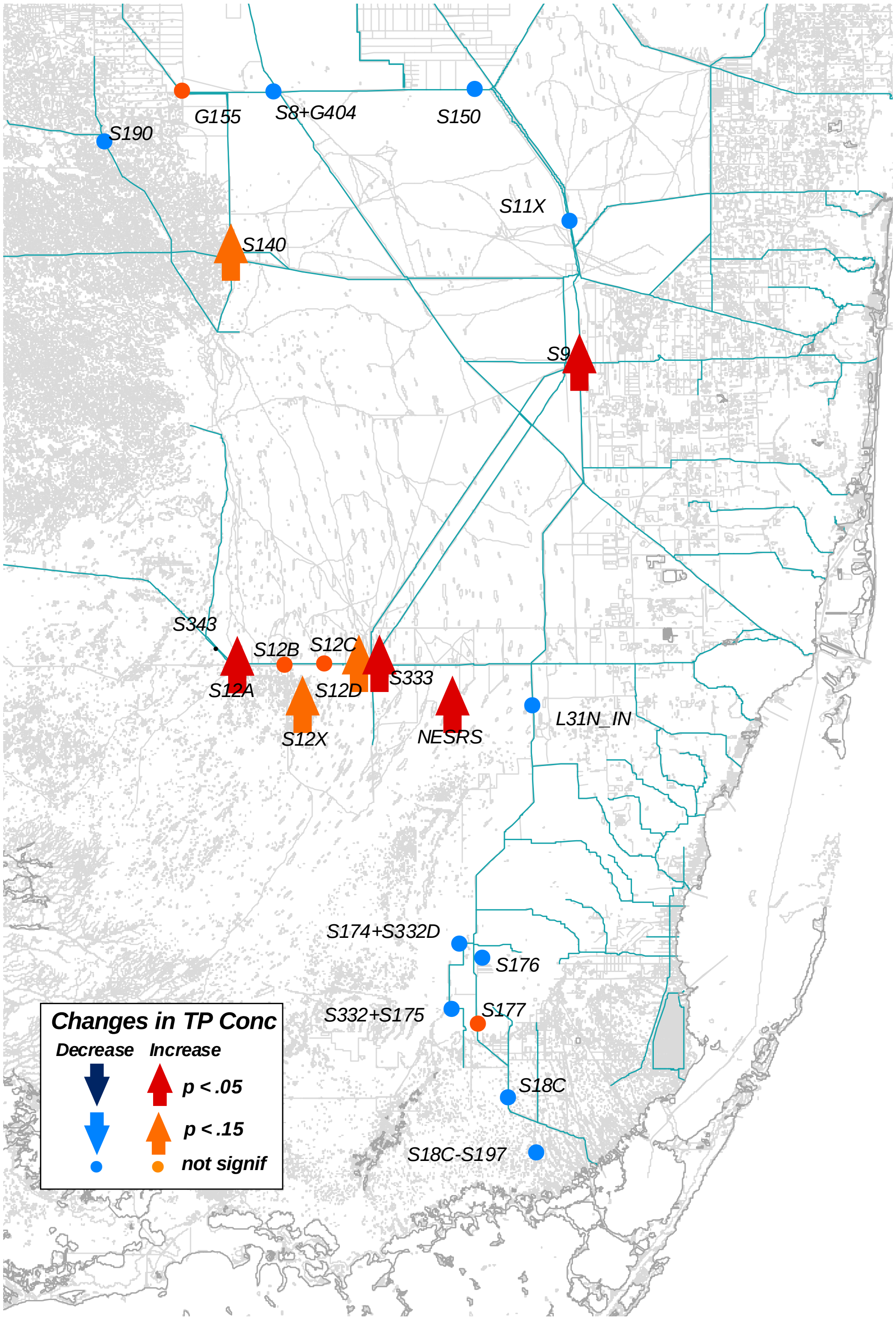


Figure 8. Map of changes in phosphorus concentration. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red p<0.05, orange p <0.15). Down arrow = significant decrease (dark blue p < .05, light blue p < 0.15). Orange circle = increase, not statistically significant (p > 0.15). Blue circle = decrease, not significant (p > 0.15). p/2 estimates the probability that the actual change was in the opposite direction from that indicated.

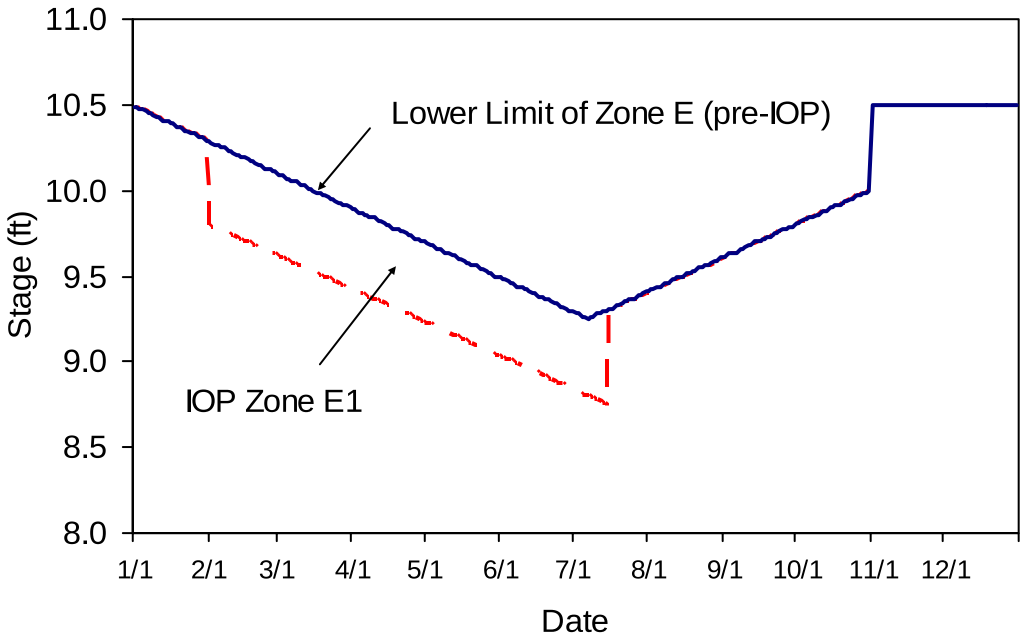


Figure 9. Change in WCA-3A regulation schedule. IOP Zone E1 allows a decrease of 0.5 feet in water levels between February and July, relative to the pre-IOP period.

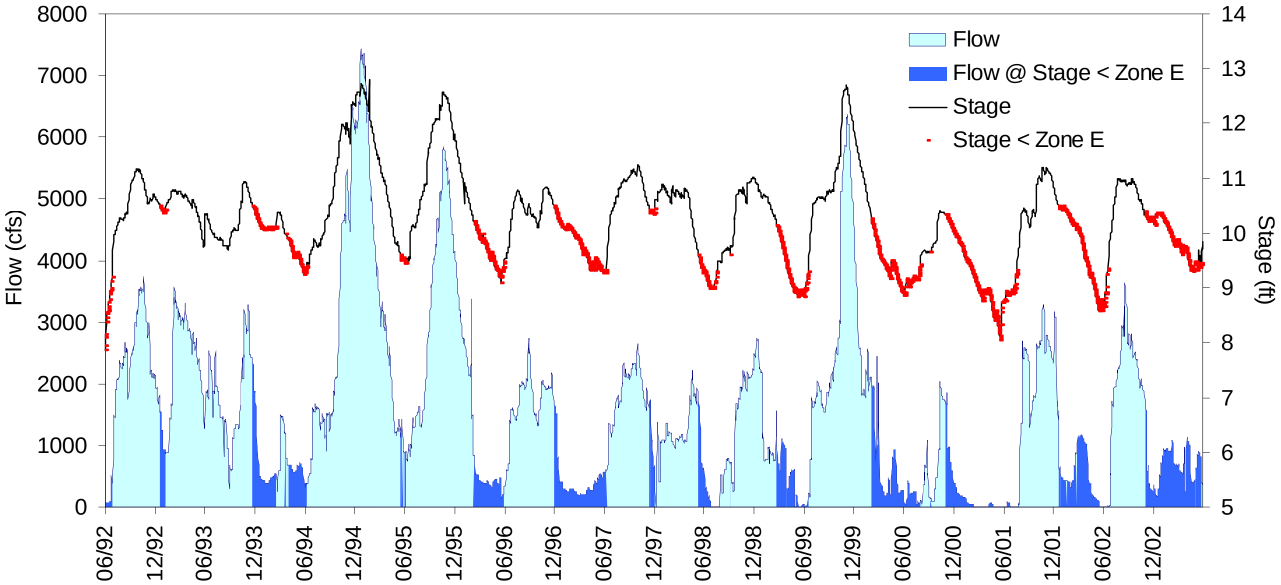


Figure 10. WCA-3A daily stage and outflow. Red line indicates days when stage was below Zone E of regulation schedule (in or below IOP Zone E1, as shown in Figure 9). Light & dark blue shaded areas are flows released above and below Zone E, respectively. Combined outflows through S12's and S333.

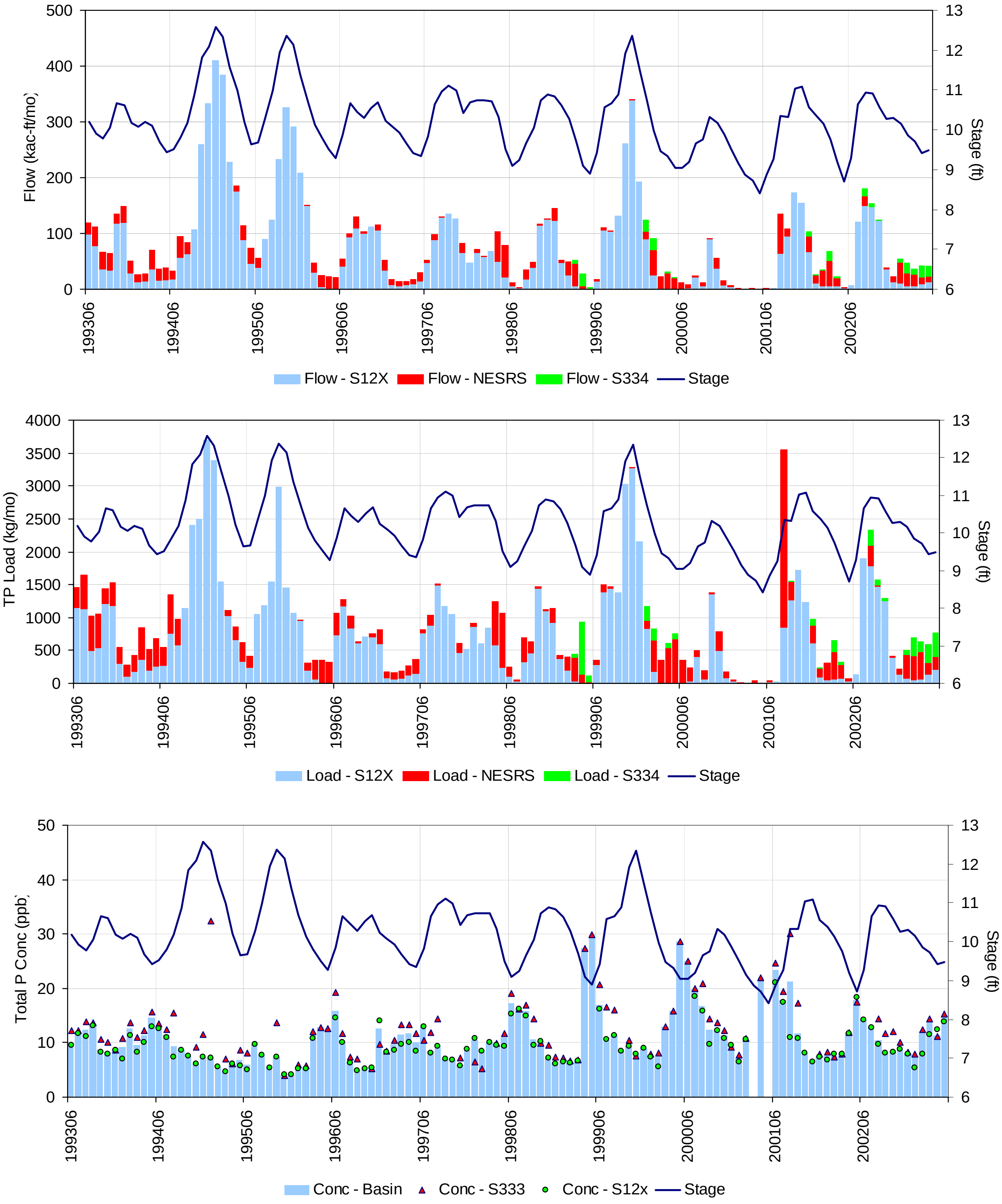
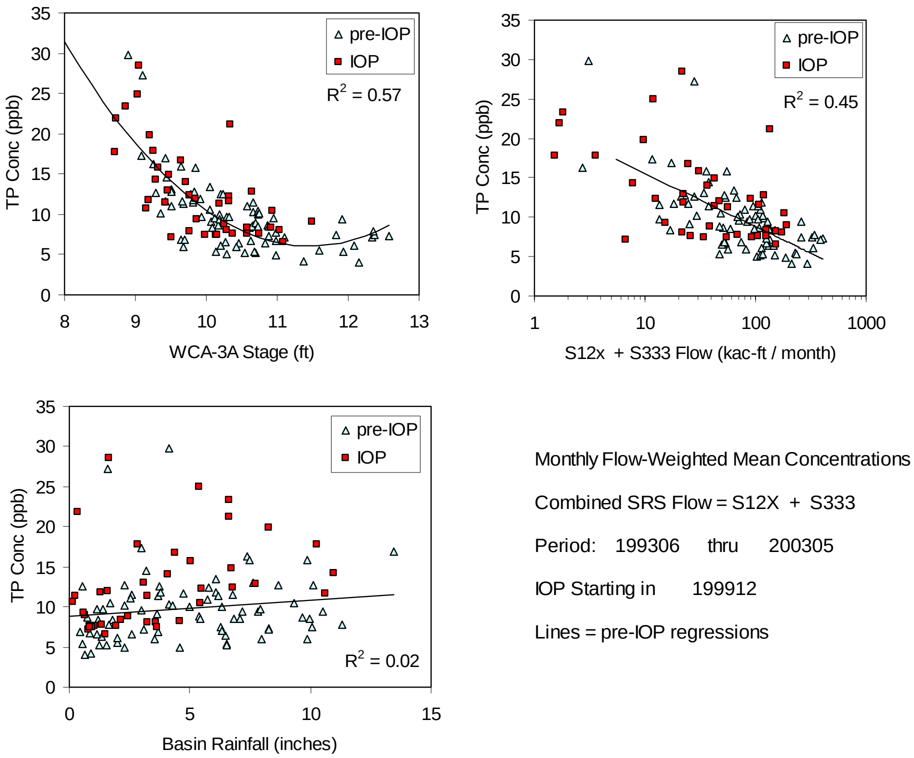


Figure 11. WCA-3A monthly stage and outflow. Combined outflows from WCA-3A through S12X, into NESRS through S333, or bypassed to L31N through S334. Bottom plot: triangles = S333 concentration; circles = S12x concentration; Bar = combined flow-weighted mean concentration; Line = WCA-3A stage.



Monthly Flow-Weighted Mean Concentrations

Combined SRS Flow = S12X + S333

Period: 199306 thru 200305

IOP Starting in 199912

Lines = pre-IOP regressions

Figure 12. Monthly TP concentrations in WCA-3A outflows vs. stage, flow, and rainfall. Combined outflows through S12X and S333. Triangles = pre-IOP period (June 1993 – November, 1999); Squares = IOP period (December 1999 – May 2003). Lines = pre-IOP regressions.

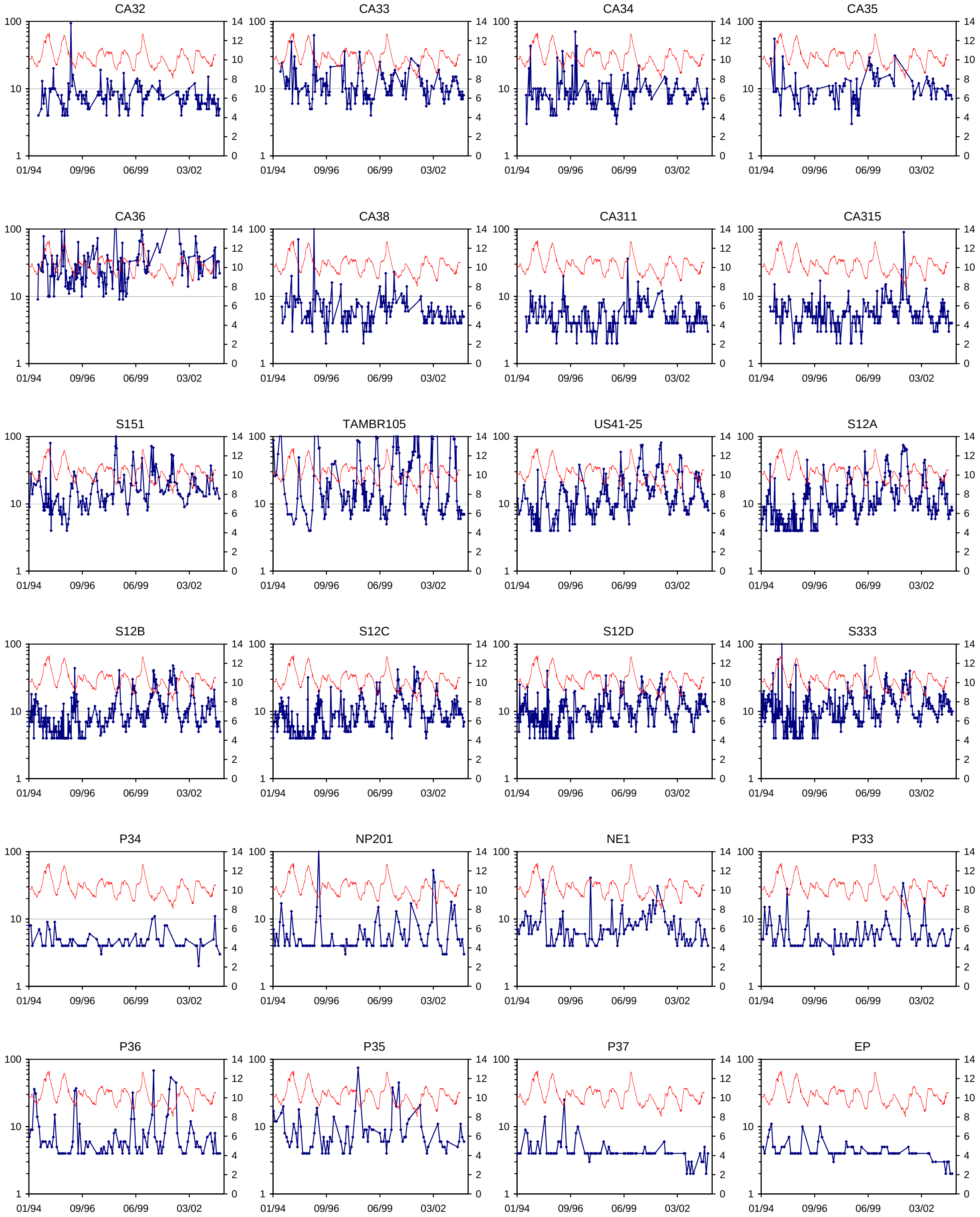


Figure 13. Total P concentration time series at regional monitoring sites. Blue lines/ left axis = sample Total P (ppb); Red lines/right axis = WCA-3A stage (ft). Sites are sorted north to south and identified in Figure 1.

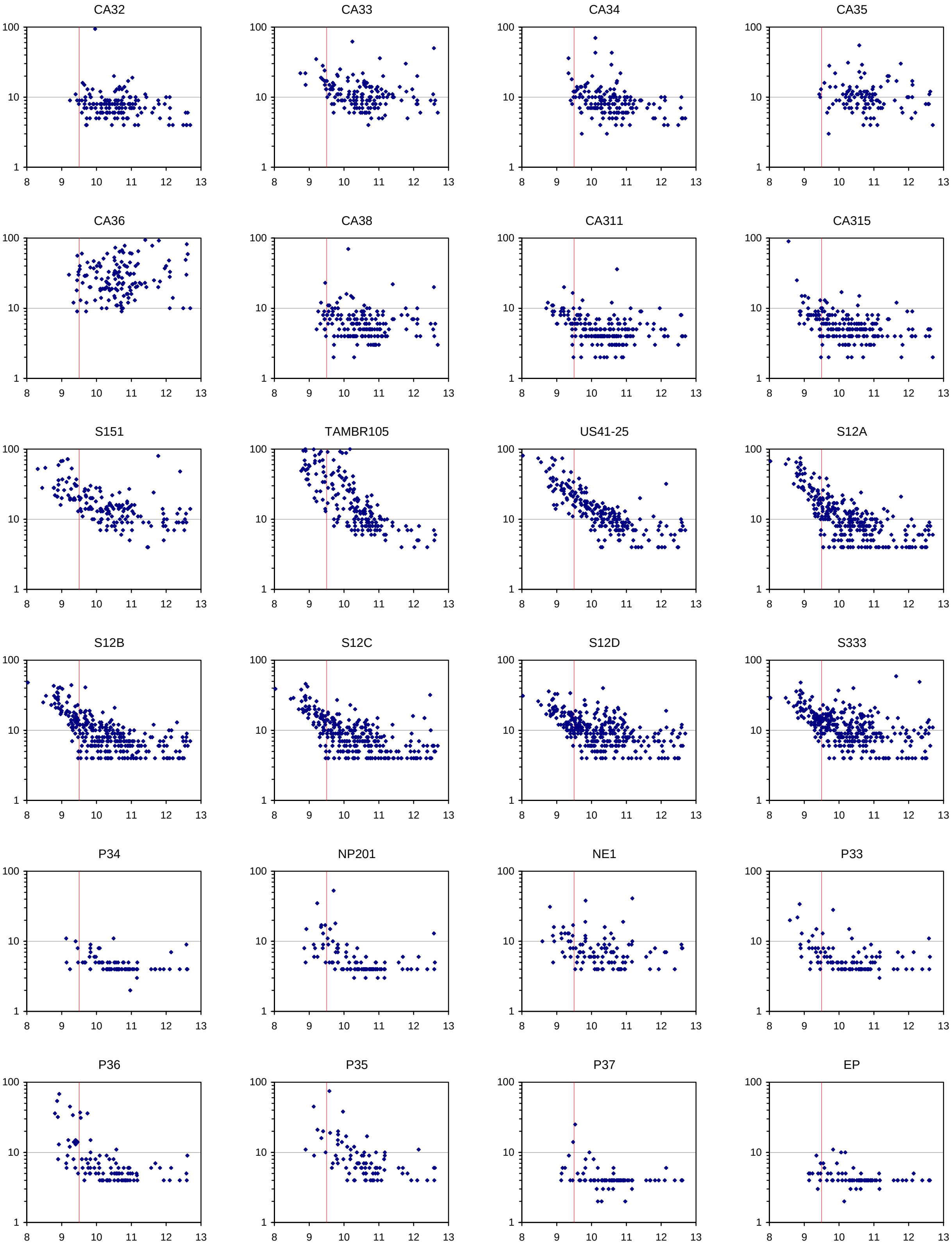


Figure 14. Total P concentration vs stage at regional monitoring sites. Left Y-Axis = Sample Total P concentration (ppb); Right Y Axis = WCA-3A Stage (ft).

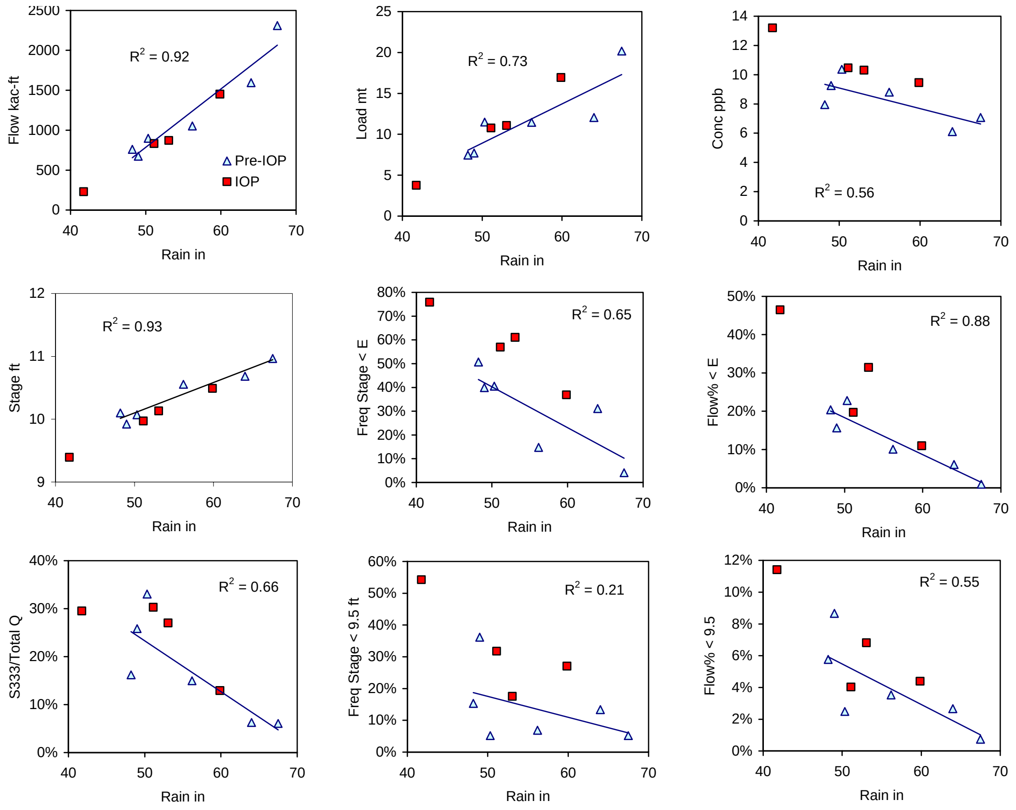
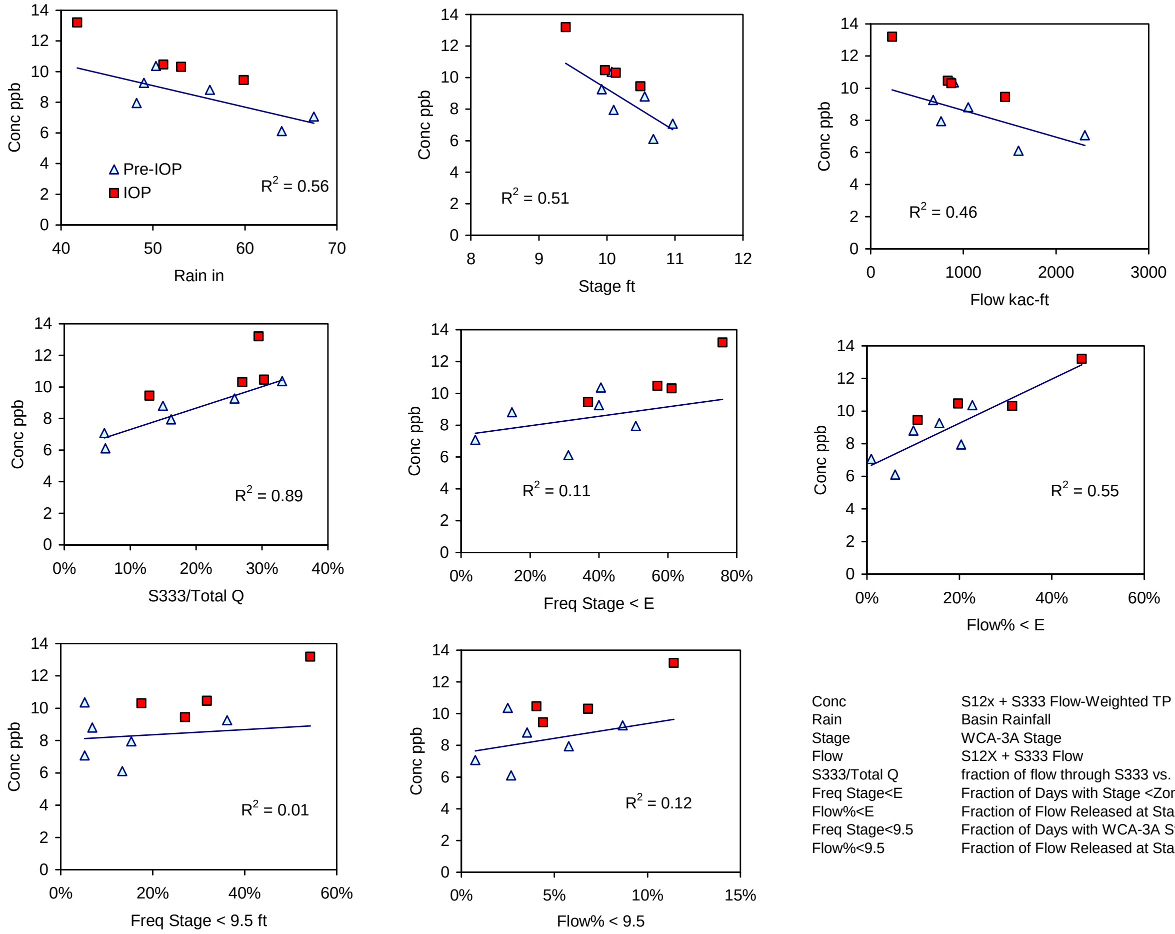


Figure 15. Phosphorus and related hydrologic variables vs. basin rainfall. Combined WCA-3A outflow through S12's & S333. Triangles = pre-IOP years (1993-1999). Squares = ISOP/IOP years (2000-2003). Lines = pre-IOP regressions. Hydrologic variables are defined in Figure 16.



Conc	S12x + S333 Flow-Weighted TP Conc
Rain	Basin Rainfall
Stage	WCA-3A Stage
Flow	S12X + S333 Flow
S333/Total Q	fraction of flow through S333 vs. S12x
Freq Stage<E	Fraction of Days with Stage <Zone E
Flow%<E	Fraction of Flow Released at Stage < Zone E
Freq Stage<9.5	Fraction of Days with WCA-3A Stage < 9.5 ft
Flow%<9.5	Fraction of Flow Released at Stage < 9.5 ft

Figure 16. WCA-3A outflow P concentration vs. basin rainfall and related hydrologic variables. Combined outflow through S12's & S333. Triangles = pre-IOP years (1993-1999). Squares = ISOP/IOP years (2000-2003). Lines = pre-IOP regressions.

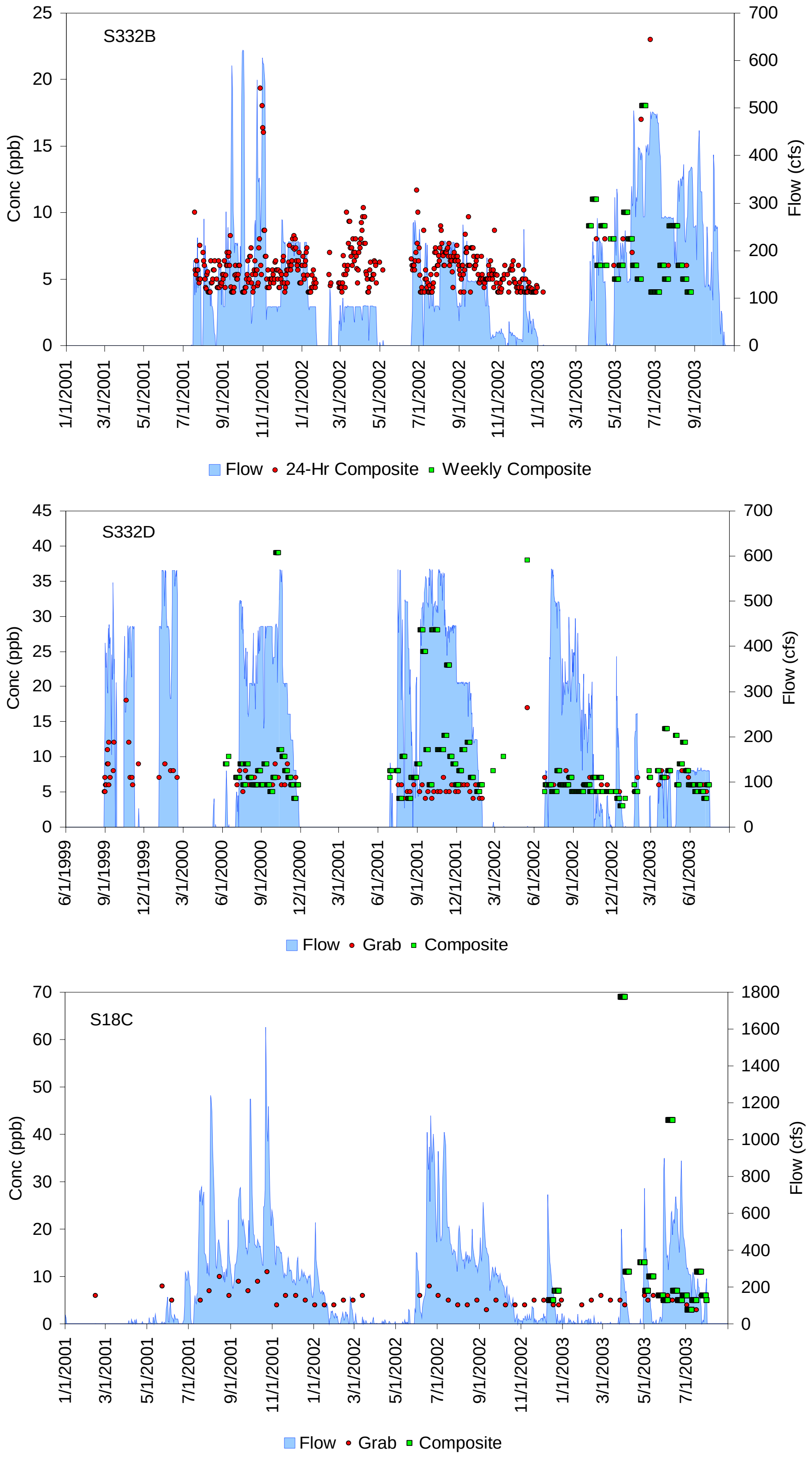


Figure 17. Comparison of Grab and Composite Samples at S332B, S332D, and S18C. Total phosphorus concentrations (ppb). Green Squares = weekly composite samples. Red Circles = grab samples (24-hr composites for S332B). Blue area = daily flow (cfs). Data are from SFWMD (S18C, S332D) and the Corps of Engineers (S332B).

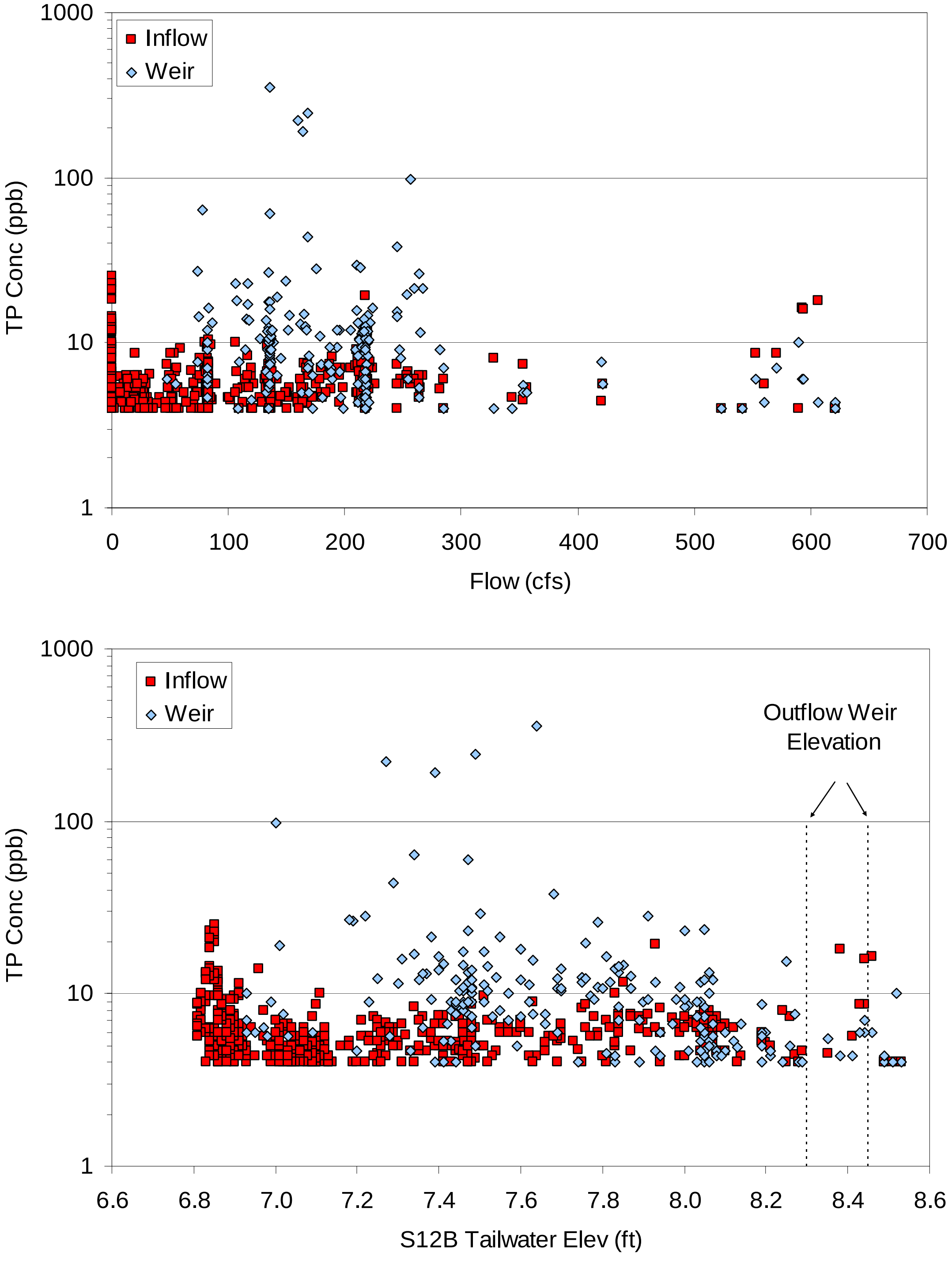


Figure 18. Phosphorus Concentrations at inflow and outflow from S332B Detention Area. Y axis = Total P concentration (ppb). X-Axis = S332B flow, cfs (Top), = S332B tailwater elevation, feet (bottom). Red squares = S332B pump station. Blue diamonds = detention basin adjacent to overflow weir. Assuming that S332B tailwater stage is representative of water level adjacent to the weir, surface overflow occurred when tailwater stage exceeded the weir elevation, which ranged from 8.3 – 8.45 ft. Data from Corps of Engineers, 2001-2003.

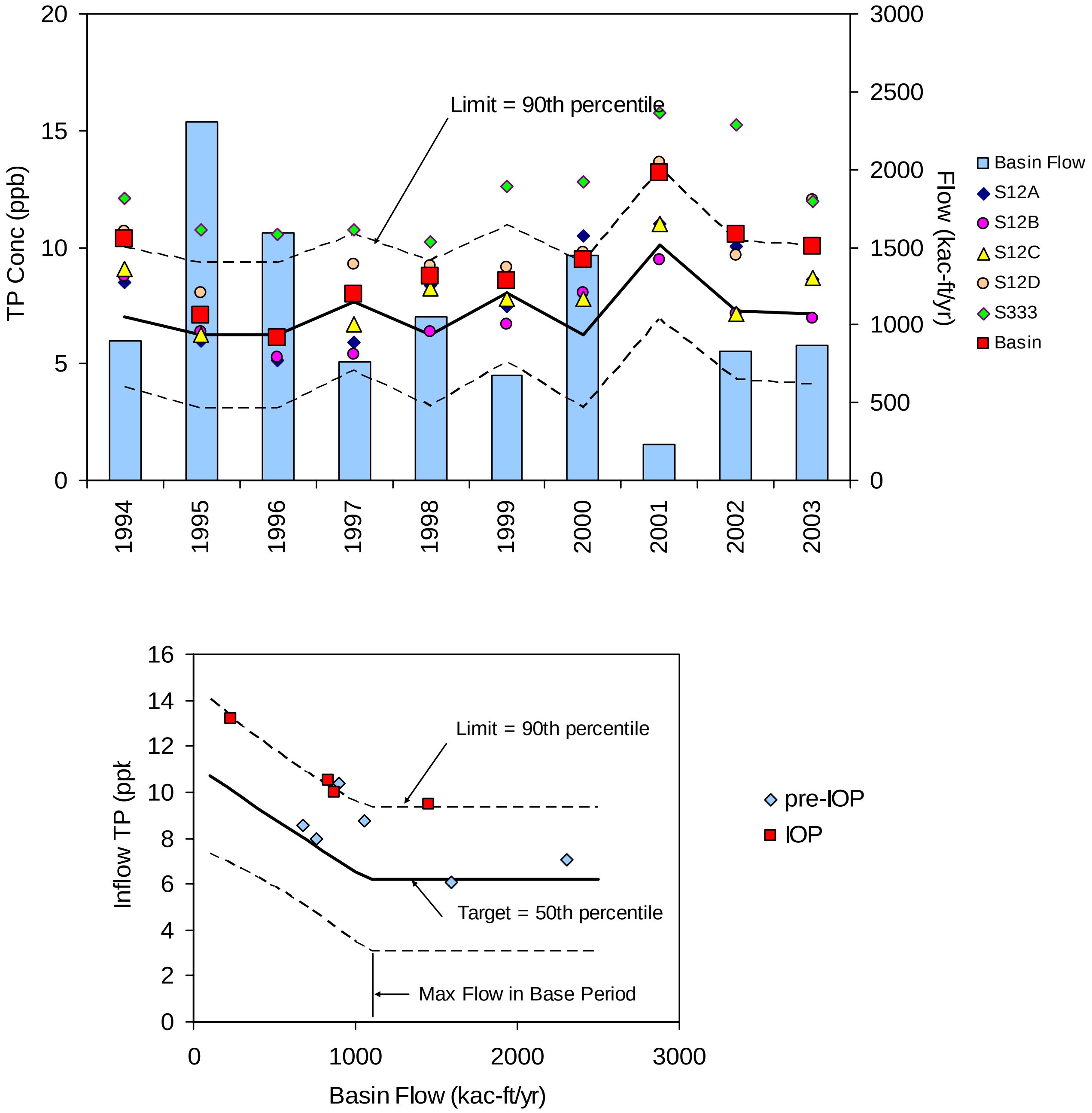


Figure 19. Consent Decree inflow P limits for Shark River Slough. Water Years 1994-2003 (June-May). Red Squares = basin flow-weighted mean (S12X+S333-S334). Other symbols show results for individual structures (not used in testing compliance). Bottom chart shows interim limit (90th percentile of 1978-1979 data) and targets as a function of basin flow (S12X+S333). The interim limits apply to the basin flow-weighted-mean concentration and is effective October 2003.

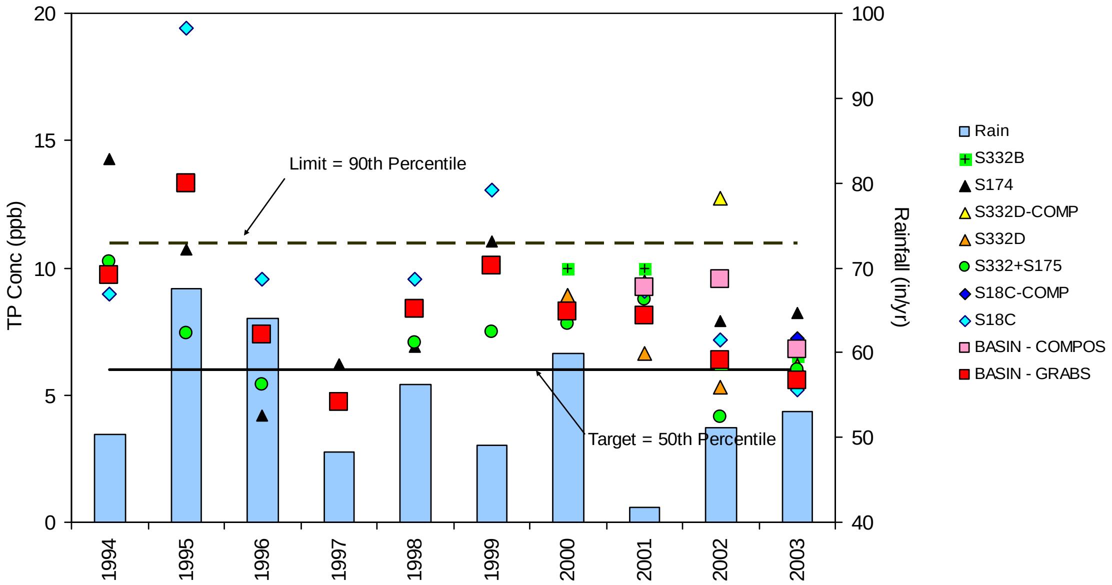


Figure 20. Consent Decree inflow P limits for Taylor Slough and Eastern Panhandle. Water Years 1994-2003 (June-May). Red Squares = basin flow-weighted mean using grab samples (S18C+S332+S175 in 1994-1999 and S18C+S332D+S174 in 2000-2003). Pink squares = basin flow-weighted mean using composite samples for S332D & S18C. Other symbols show results for individual structures (not used in testing compliance). The long-term yearly limit of 11 ppb (effective 2006) represents the 90th percentile of 1983- 1984 data and is applicable to the basin flow-weighted mean. The target (6 ppb) represents the 50th percentile

Appendix

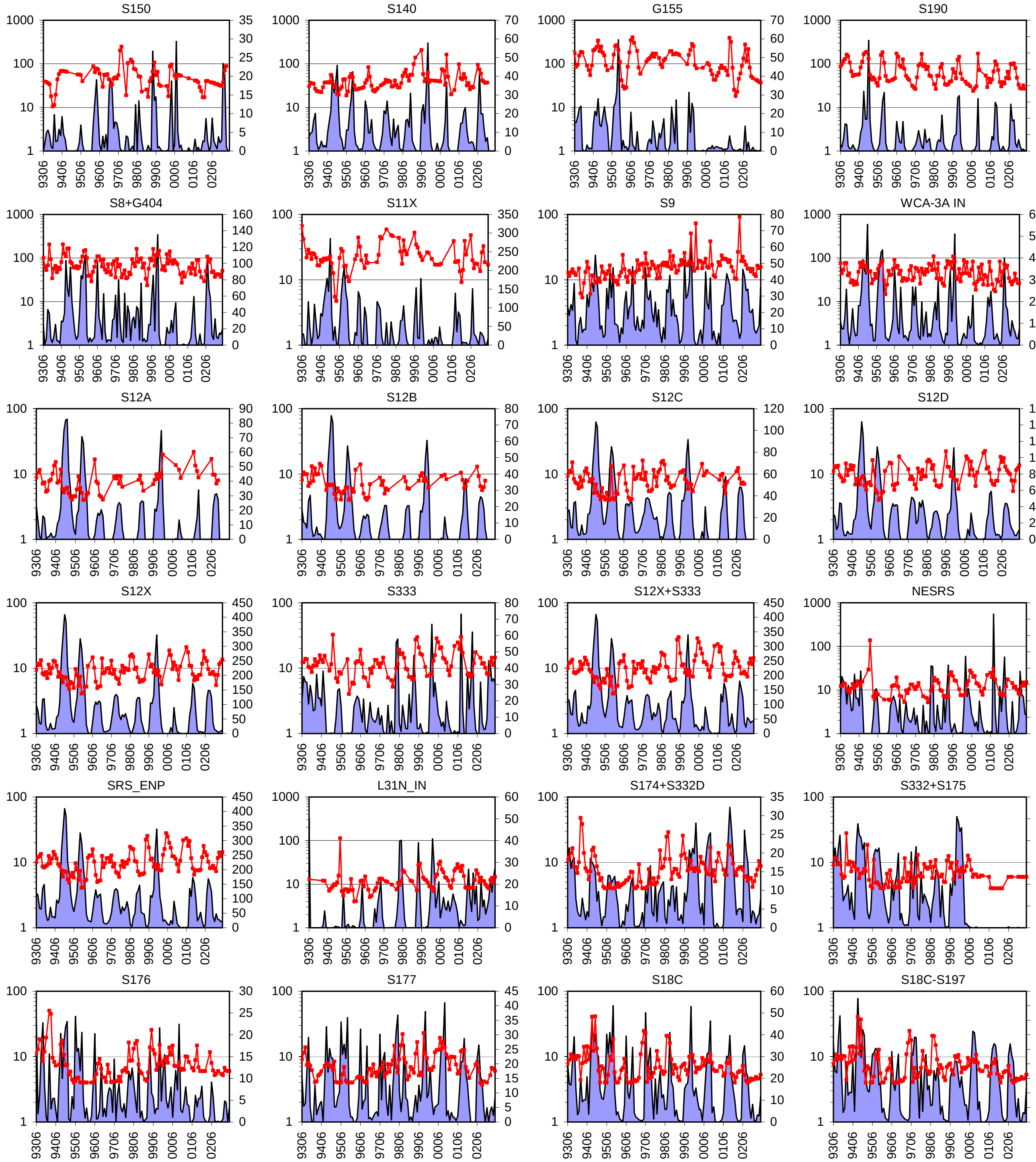
Further details posted at http://www.wwwalker.net/iop

A-1. Table of Results. All = 1994-2003; pre-IOP = 1994-1999; IOP = 2000-2003; Increase = IOP mean – pre-IOP Mean. % Increase = increase as percent of pre-IOP mean. SE = standard Error. R2 = regression model coefficient of determination. P = significance level, two-tailed test (* p < .15, ** p < .05)

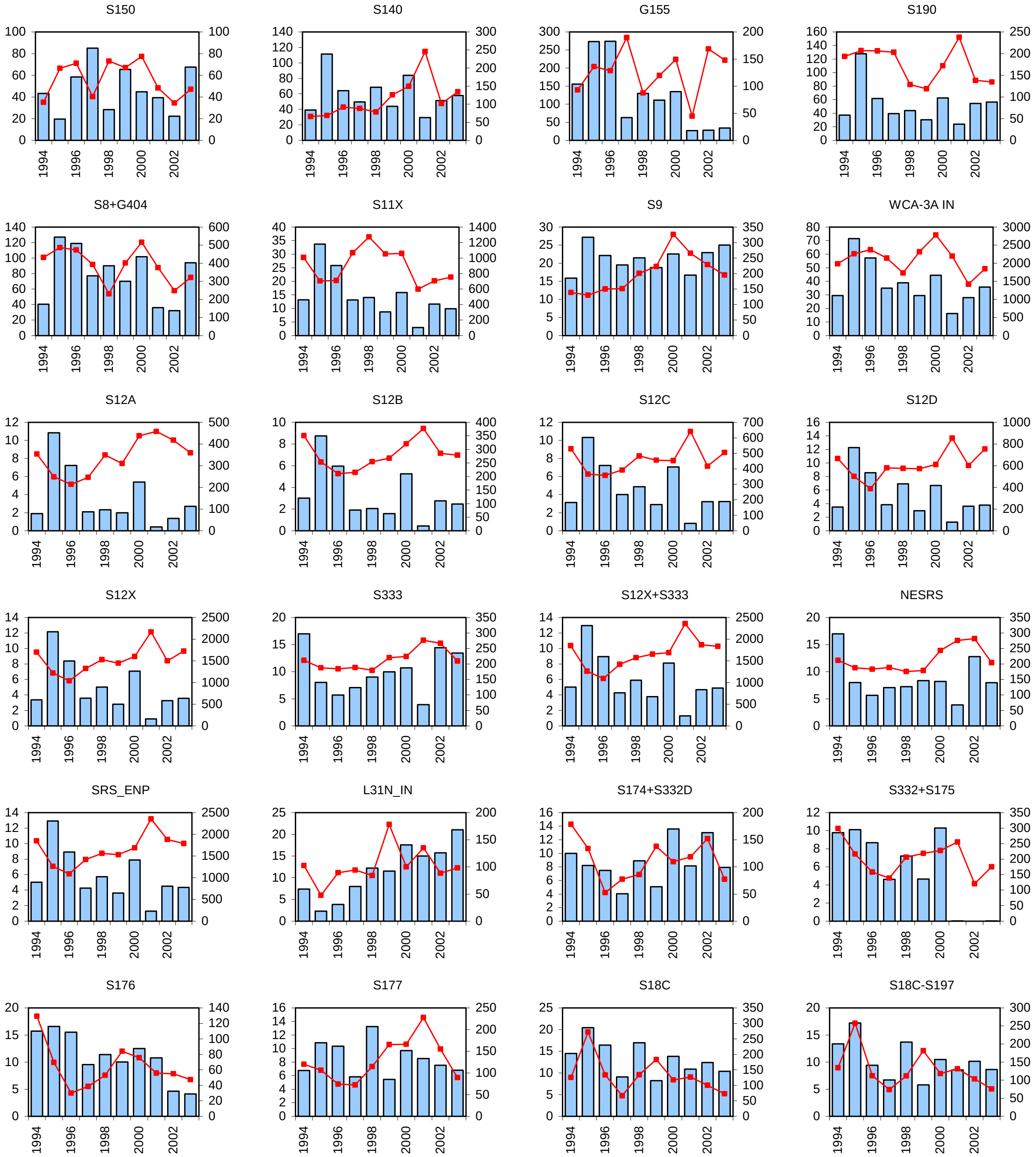
			Observed Values			Rainfall-Adjusted Values									
Site	Variable	Units	All	pre-IOP	IOP	All	pre-IOP	IOP	Increase	Inc_SE	% Incr	%Inc_SE	R^2	p	
S150	Flow	kac-ft/yr	47.4	50.0	43.5	47.4	51.8	40.7	-11.1	15.0	-23%	29%	0.16	0.48	
S150	Load	kg/yr	3231.6	3468.5	2876.2	3231.6	3466.9	2878.6	-588.3	1169.6	-17%	34%	0.04	0.63	
S150	Conc	ppb	56.1	58.9	51.8	56.1	56.6	55.3	-1.3	10.0	-2%	18%	0.39	0.90	
S150	FWMC	ppb	55.2	56.2	53.5	55.2	54.2	57.3	3.1		6%				
S140	Flow	kac-ft/yr	128.4	134.5	119.3	128.4	123.7	135.5	11.8	16.5	9%	13%	0.82	0.50	
S140	Load	kg/yr	7925.6	6463.5	10118.8	7925.6	6033.8	10763.4	4729.7	1523.6	78%	25%	0.63	0.02	**
S140	Conc	ppb	53.7	40.4	73.6	53.7	42.5	70.5	28.1	12.2	66%	29%	0.59	0.06	*
S140	FWMC	ppb	50.0	38.9	68.7	50.0	39.5	64.4	24.9		63%				
G155	Flow	kac-ft/yr	82.0	111.9	37.3	82.0	102.0	52.2	-49.8	17.6	-61%	17%	0.86	0.03	**
G155	Load	kg/yr	19061.9	25379.8	9585.1	19061.9	22696.0	13610.8	-9085.1	4268.8	-40%	19%	0.86	0.07	*
G155	Conc	ppb	189.5	188.4	191.2	189.5	183.9	198.0	14.1	46.4	8%	25%	0.09	0.77	
G155	FWMC	ppb	188.2	183.8	208.2	188.2	180.3	211.4	31.1		17%				
S190	Flow	kac-ft/yr	84.0	88.6	77.0	84.0	79.6	90.5	10.9	18.3	13%	23%	0.72	0.57	
S190	Load	kg/yr	11734.2	13075.4	9722.4	11734.2	11647.4	11864.5	217.1	3759.3	2%	32%	0.62	0.96	
S190	Conc	ppb	111.3	112.7	109.1	111.3	112.7	109.1	-3.6	20.2	-3%	18%	0.00	0.86	
S190	FWMC	ppb	113.2	119.6	102.3	113.2	118.5	106.2	-12.3		-10%				
S8+G404	Flow	kac-ft/yr	337.2	373.8	282.4	337.2	346.5	323.3	-23.2	56.6	-7%	16%	0.74	0.69	
S8+G404	Load	kg/yr	39359.9	44182.9	32125.6	39359.9	39794.5	38708.1	-1086.4	9430.8	-3%	24%	0.72	0.91	
S8+G404	Conc	ppb	90.5	94.0	85.3	90.5	91.9	88.4	-3.5	15.5	-4%	17%	0.19	0.83	
S8+G404	FWMC	ppb	94.5	95.7	92.2	94.5	93.0	97.0	4.0		4%				
S11X	Flow	kac-ft/yr	521.4	633.5	353.3	521.4	573.5	443.4	-130.1	74.1	-25%	13%	0.90	0.12	*
S11X	Load	kg/yr	16129.8	19828.4	10581.8	16129.8	18443.4	12659.4	-5784.0	1965.6	-31%	11%	0.90	0.02	**
S11X	Conc	ppb	25.5	27.7	22.3	25.5	27.9	21.9	-6.0	4.3	-22%	15%	0.22	0.21	
S11X	FWMC	ppb	25.1	25.4	24.3	25.1	26.1	23.1	-2.9		-11%				
S9	Flow	kac-ft/yr	247.7	243.1	254.5	247.7	235.0	266.6	31.5	17.3	13%	7%	0.70	0.11	*
S9	Load	kg/yr	5244.5	4225.0	6773.7	5244.5	4090.7	6975.2	2884.5	788.4	71%	19%	0.66	0.01	**
S9	Conc	ppb	17.2	14.2	21.8	17.2	14.3	21.7	7.4	2.8	52%	20%	0.54	0.03	**
S9	FWMC	ppb	17.2	14.1	21.6	17.2	14.1	21.2	7.1		50%				
WCA-3A IN	Flow	kac-ft/yr	1448.2	1635.4	1167.3	1448.2	1512.2	1352.1	-160.1	113.8	-11%	8%	0.94	0.20	
WCA-3A IN	Load	kg/yr	102687.6	116623.5	81783.6	102687.6	106172.6	97460.1	-8712.5	16076.4	-8%	15%	0.84	0.60	
WCA-3A IN	Conc	ppb	56.1	56.9	54.9	56.1	56.3	56.0	-0.3	7.4	-1%	13%	0.09	0.97	
WCA-3A IN	FWMC	ppb	57.4	57.8	56.8	57.4	56.9	58.4	1.5		3%				
S12A	Flow	kac-ft/yr	151.1	183.3	102.8	151.1	155.6	144.4	-11.2	38.9	-7%	25%	0.86	0.78	
S12A	Load	kg/yr	1352.8	1412.6	1263.2	1352.8	1190.3	1596.6	406.3	315.0	34%	26%	0.84	0.24	
S12A	Conc	ppb	8.1	6.9	10.0	8.1	7.0	9.8	2.8	0.8	40%	12%	0.72	0.01	**
S12A	FWMC	ppb	7.3	6.2	9.9	7.3	6.2	9.0	2.8		45%				
S12B	Flow	kac-ft/yr	136.7	155.0	109.2	136.7	133.9	140.9	7.0	28.0	5%	21%	0.87	0.81	
S12B	Load	kg/yr	1137.1	1210.6	1027.0	1137.1	1048.6	1270.0	221.4	290.2	21%	28%	0.77	0.47	
S12B	Conc	ppb	7.0	6.5	7.9	7.0	6.6	7.7	1.1	0.8	17%	12%	0.42	0.19	
S12B	FWMC	ppb	6.7	6.3	7.6	6.7	6.3	7.3	1.0		15%				
S12C	Flow	kac-ft/yr	272.7	315.4	208.6	272.7	281.1	260.0	-21.1	34.5	-8%	12%	0.92	0.56	
S12C	Load	kg/yr	2458.8	2723.5	2061.7	2458.8	2467.3	2445.9	-21.5	297.6	-1%	12%	0.90	0.94	
S12C	Conc	ppb	7.9	7.4	8.6	7.9	7.6	8.3	0.7	0.7	10%	10%	0.56	0.35	
S12C	FWMC	ppb	7.3	7.0	8.0	7.3	7.1	7.6	0.5		7%				
S12D	Flow	kac-ft/yr	333.7	396.2	240.0	333.7	353.9	303.5	-50.5	40.2	-15%	11%	0.93	0.25	
S12D	Load	kg/yr	3691.4	4054.4	3147.0	3691.4	3684.7	3701.4	16.7	580.9	0%	16%	0.82	0.98	
S12D	Conc	ppb	9.8	8.8	11.3	9.8	9.0	10.9	1.8	0.8	20%	9%	0.74	0.06	*
S12D	FWMC	ppb	9.0	8.3	10.6	9.0	8.4	9.9	1.4		17%				

A-1 Continued.

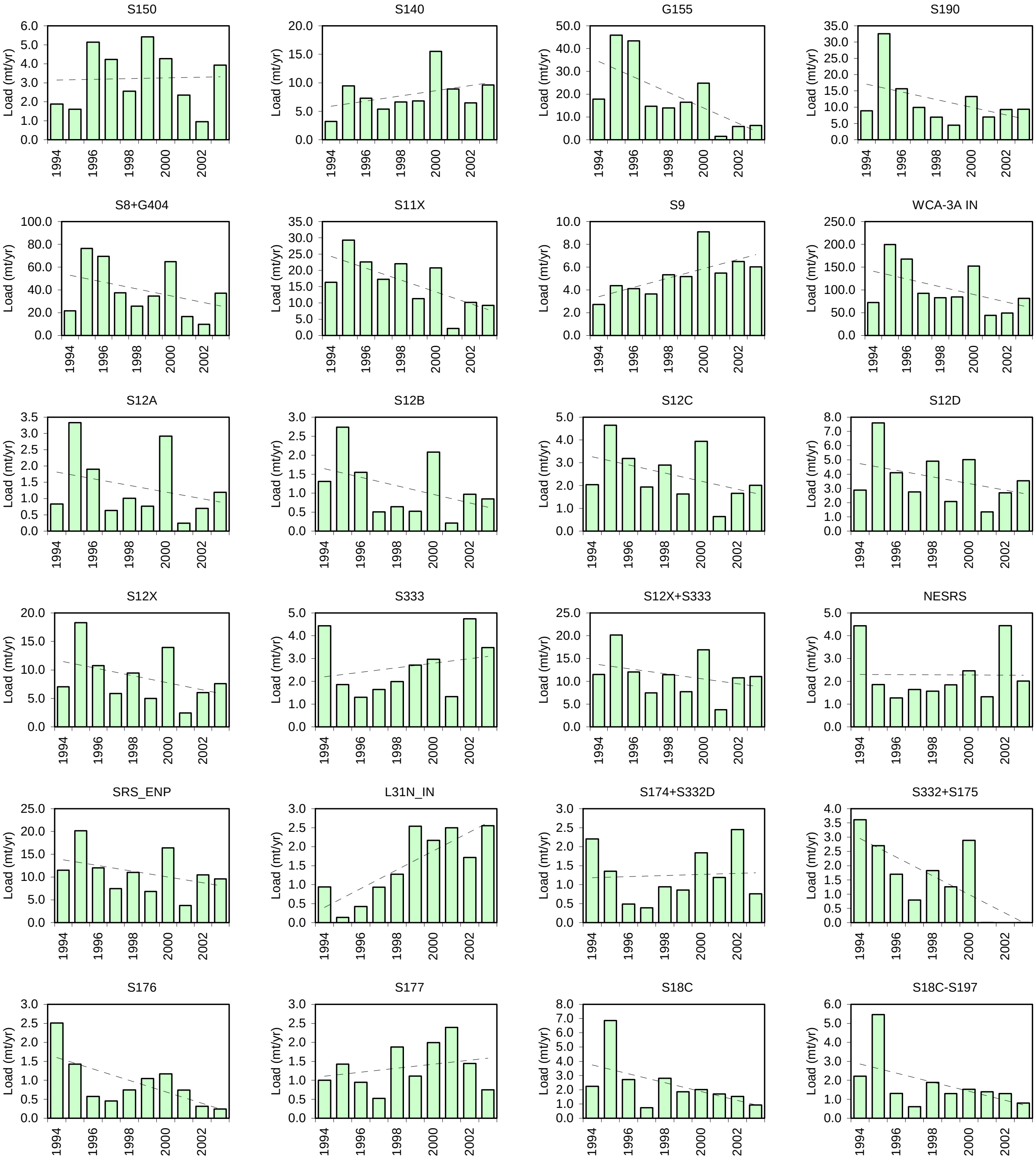
			Observed Values			Rainfall-Adjusted Values									
Site	Variable	Units	All	pre-IOP	IOP	All	pre-IOP	IOP	Increase	Inc_SE	% Incr	%Inc_SE	R^2	p	
S12X	Flow	kac-ft/yr	894.2	1049.9	660.6	894.2	924.5	848.7	-75.8	119.1	-8%	13%	0.93	0.54	
S12X	Load	kg/yr	8640.1	9401.0	7498.8	8640.1	8390.9	9013.9	622.9	1222.5	7%	15%	0.88	0.63	
S12X	Conc	ppb	8.5	7.7	9.8	8.5	7.9	9.4	1.5	0.7	19%	9%	0.69	0.08	*
S12X	FWMC	ppb	7.8	7.3	9.2	7.8	7.4	8.6	1.3		17%				
S333	Flow	kac-ft/yr	173.6	165.4	186.0	173.6	165.7	185.6	19.9	54.0	11%	33%	0.02	0.72	
S333	Load	kg/yr	2644.4	2321.4	3129.1	2644.4	2345.2	3093.3	748.1	896.7	32%	38%	0.12	0.43	
S333	Conc	ppb	12.3	11.2	13.9	12.3	11.3	13.7	2.3	0.8	20%	7%	0.73	0.02	**
S333	FWMC	ppb	12.3	11.4	13.6	12.3	11.5	13.5	2.0		18%				
S12X+S333	Flow	kac-ft/yr	1067.8	1215.3	846.6	1067.8	1090.2	1034.3	-55.9	106.9	-5%	10%	0.94	0.62	
S12X+S333	Load	kg/yr	11284.6	11722.3	10627.9	11284.6	10736.1	12107.2	1371.1	1511.7	13%	14%	0.82	0.39	
S12X+S333	Conc	ppb	9.3	8.3	10.8	9.3	8.6	10.4	1.9	0.6	22%	7%	0.82	0.02	**
S12X+S333	FWMC	ppb	8.6	7.8	10.2	8.6	8.0	9.5	1.5		19%				
NESRS	Flow	kac-ft/yr	150.5	155.1	143.6	150.5	156.6	141.4	-15.2	49.2	-10%	31%	0.02	0.77	
NESRS	Load	kg/yr	2283.3	2099.5	2559.2	2283.3	2126.6	2518.5	392.0	883.6	18%	42%	0.05	0.67	
NESRS	Conc	ppb	12.2	10.7	14.4	12.2	10.8	14.2	3.4	0.9	31%	9%	0.72	0.01	**
NESRS	FWMC	ppb	12.3	11.0	14.4	12.3	11.0	14.4	3.4		31%				
SRS_ENP	Flow	kac-ft/yr	1044.7	1205.0	804.3	1044.7	1081.1	990.2	-91.0	117.5	-9%	11%	0.93	0.46	
SRS_ENP	Load	kg/yr	10923.5	11500.5	10058.0	10923.5	10517.5	11532.4	1014.9	1560.9	10%	15%	0.81	0.54	
SRS_ENP	Conc	ppb	9.2	8.1	10.8	9.2	8.4	10.4	2.0	0.7	24%	8%	0.81	0.02	**
SRS_ENP	FWMC	ppb	8.5	7.7	10.1	8.5	7.9	9.4	1.6		20%				
L31N_IN	Flow	kac-ft/yr	91.7	60.4	138.6	91.7	62.9	134.9	72.0	18.9	79%	30%	0.74	0.01	**
L31N_IN	Load	kg/yr	1516.2	1039.0	2232.0	1516.2	1132.7	2091.5	958.8	406.1	85%	36%	0.66	0.05	*
L31N_IN	Conc	ppb	12.7	12.4	13.2	12.7	13.1	12.2	-0.9	2.4	-7%	19%	0.46	0.71	
L31N_IN	FWMC	ppb	13.4	13.9	13.0	13.4	14.6	12.6	-2.0		-14%				
S174+S332D	Flow	kac-ft/yr	108.0	91.0	133.5	108.0	87.4	138.8	51.4	20.5	48%	23%	0.50	0.04	**
S174+S332D	Load	kg/yr	1246.2	1038.5	1557.9	1246.2	1027.2	1574.8	547.5	500.6	53%	49%	0.15	0.31	
S174+S332D	Conc	ppb	9.0	8.9	9.1	9.0	9.1	8.9	-0.2	2.3	-2%	26%	0.07	0.93	
S174+S332D	FWMC	ppb	9.3	9.2	9.5	9.3	9.5	9.2	-0.3		-3%				
S332+S175	Flow	kac-ft/yr	161.5	219.0	75.4	161.5	203.2	99.1	-104.1	58.4	-64%	29%	0.63	0.12	*
S332+S175	Load	kg/yr	1479.5	1982.0	725.8	1479.5	1858.4	911.2	-947.2	765.5	-51%	41%	0.41	0.26	
S332+S175	Conc	ppb	6.9	7.1	6.7	6.9	7.2	6.5	-0.6	1.4	-8%	19%	0.05	0.68	
S332+S175	FWMC	ppb	7.4	7.3	7.8	7.4	7.4	7.4	0.0		1%				
S176	Flow	kac-ft/yr	77.5	91.9	56.0	77.5	89.5	59.6	-29.9	16.4	-39%	18%	0.49	0.11	*
S176	Load	kg/yr	920.9	1124.6	615.2	920.9	1125.2	614.3	-510.9	473.9	-45%	42%	0.15	0.32	
S176	Conc	ppb	9.1	9.6	8.3	9.1	9.8	8.1	-1.7	3.0	-18%	30%	0.06	0.58	
S176	FWMC	ppb	9.6	9.9	8.9	9.6	10.2	8.3	-1.8		-18%				
S177	Flow	kac-ft/yr	132.8	136.7	127.0	132.8	131.1	135.4	4.3	23.4	3%	18%	0.39	0.86	
S177	Load	kg/yr	1345.1	1146.8	1642.7	1345.1	1140.0	1652.9	512.9	408.9	45%	36%	0.19	0.25	
S177	Conc	ppb	8.3	7.0	10.2	8.3	7.2	9.8	2.6	1.8	36%	25%	0.42	0.20	
S177	FWMC	ppb	8.2	6.8	10.5	8.2	7.0	9.9	2.8		40%				
S18C	Flow	kac-ft/yr	186.3	199.8	166.1	186.3	190.4	180.3	-10.1	24.4	-5%	13%	0.65	0.69	
S18C	Load	kg/yr	2339.3	2871.5	1541.0	2339.3	2615.7	1924.7	-691.0	881.5	-26%	34%	0.55	0.46	
S18C	Conc	ppb	9.5	10.9	7.4	9.5	10.5	8.1	-2.4	2.6	-23%	25%	0.36	0.39	
S18C	FWMC	ppb	10.2	11.6	7.5	10.2	11.1	8.7	-2.5		-22%				
S18C-S197	Flow	kac-ft/yr	155.9	165.3	141.7	155.9	158.4	152.0	-6.5	31.6	-4%	20%	0.37	0.84	
S18C-S197	Load	kg/yr	1779.1	2129.3	1253.6	1779.1	1957.9	1510.8	-447.1	822.2	-23%	42%	0.39	0.60	
S18C-S197	Conc	ppb	8.7	9.7	7.1	8.7	9.4	7.6	-1.8	2.4	-20%	26%	0.24	0.47	
S18C-S197	FWMC	ppb	9.2	10.4	7.2	9.2	10.0	8.1	-2.0		-20%				



A-2 - Monthly flows and concentrations. Red lines / left axis = monthly flow-weighted mean TP concentration. Blue areas / right axis = flow (kac-ft/month)



A-3. Yearly flows and concentrations. Red lines / left axis = yearly flow-weighted mean TP concentration. Blue bars / right axis = flow (kac-ft/yr). Water years 1994-2003.



A-4. Yearly Total P loads. Dotted line = linear trend. Water years 1994-2003.