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Analysis of Recent Phosphorus Data from Shark River Slough Inflows to Everglades National Park

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Background

Appendix A of the Settlement Agreement (SA) describes interim and long-term phosphorus limits for inflows to Everglades National Park The equations were developed to provide inflow P concentrations equivalent to those which occurred in the OFW base period (1978-1979), while accounting for natural hydrologic variations and other random variations, as required under the OFW statute.

Appendix E of the Everglades Swim Plan (SFWMD, 1992) describes the derivation of the limits based upon monitoring data from Water Years 1978-1990. The interim limits were derived using data from structures S12A-D and S333 that discharge flow from WCA-3A into ENP along the Tamiami Trail. Historically, there has been an increasing gradient in P concentrations from west to east (S12A-→S333) that reflects a decreasing influence of overland sheet flow from the WCA-3A marsh.and increasing influence of channelized flows that transport flow and phosphorus along the Miami Canal and L67 levee. To reduce the influence of channelized flows, the long-term limits were derived using data from S12A-D only. WY 1985 & 1986 were excluded from the derivation of both the interim and long-term limits because of atypical operating conditions (intentional delivery of canal flows to each structure, resulting in unusually high P concentrations).

Walker (1999, 2000) discusses the underlying model and monitoring results through WY 1996. SFMWD summarizes results in quarterly reports to the TOC, as summarized annually in the Everglades Consolidated Report (SFWMD, 2002).

The attached Table 1 (from Walker, 1999) summarizes the statistical derivation of the interim limits using a regression model of the following form:

Conc. = Mean + Flow Effect + Trend Effect + Random Effect

The total basin flow is used as surrogate hydrologic adjustor and reflects a tendency for concentrations to be higher in dry years and lower in wet years. The correlation with flow could be related to dilution by rainfall, variations in water level, and/or changes in flow distribution. The trend term represents an underlying increasing trend (0.59 ± 0.15 ppb/yr) over the 1978-1990 period, when adjusted for variations in flow. The random term reflects sampling variations and other random factors not represented in the model, as estimated from the standard error of the regression equation.

The trend term reflects increasing concentrations at the individual S12A-D structures (4-8%/yr, Walker, 1991) and an increasing proportion of flow through S333 over the 1978-1990 period. The first flow through S333 occurred in January 1979. The proportion of flow through S333 was 0-12% in WY 1978-1984, as compared with 32-64% in WY 1987-1990 (Figure 1). The SA limits were designed to factor out these influences and provide inflow water quality equivalent to 1978-1979 conditions.

As described in Table 1, the flow term can be used to adjust for year-to-year variations in hydrology and focus on tracking the long-term-average concentration:

Flow-Adjusted Conc. = Mean + Trend Effect + Random Effect

Compliance with the interim limit will provide a long-term flow-adjusted concentration of ~8.7 ppb or less. Long-term compliance will provide a long-term mean of ~8.6 ppb, but with a lower yearly limit because the regression model for the long-term dataset had a lower residual standard error (1.2 ppb vs. 1.9 ppb, SFWMD,1992). This is remarkably similar to background P concentrations found in unimpacted areas of WCA-2A & WCA-1 (SFWMD, 2002).

The trend term of the regression model can be used to adjust the data in each year between 1980 and 1990 back to the 1978-1979 base period:

Detrended Conc. = 1978-1979 Mean + Flow Effect + Random Effect

The target and limit correspond to the 50th and 90th percentile of the 1978-1979 distribution, accounting for variations in flow:

Target = 1978-1979 Mean + Flow Effect

Limit = Target + Random Effect

Details are given in Table 1. For simplicity, the analysis below focuses on interim limits. It also uses SRS inflow concentrations computed using the entire S333 flow, pending further discussion of the appropriate computation procedure to be used when flow is released through S334, as occurred in WY 1999 and 2000.

Recent Data

Concentration and hydrologic time series over the 1978-2001 period are shown in Figure 1. Hydrologic data include three factors that are correlated with each other and with inflow concentrations: basin total flow, WCA-3A average stage, and the portion of flow through S333 (vs. S12's). The stage values (SFWMD DBKEY=15943) are reported to SFWMD by the Corps of Engineers. While the stage record is reasonably complete, information on the consistency of these values throughout the record is not readily available. Changes in the stations used to compute the average might influence comparisons between historical and recent data. Further investigation and development of consistent stage record(s) for WCA-3A are recommended to support TOC interpretations of future compliance data.

The apparent increasing trend in inflow concentration between 1995 and 2001 (Figure 1) has been discussed at TOC meetings and triggered this investigation. The apparent trend occurred during a period of decreasing flows, decreasing stage, and increasing proportion of flow through S333. The last factor is a consequence of the decreasing stage and changes in water management associated with efforts to protect the Cape Sable sea sparrow. The maximum flow in the model calibration period (1978-1990) was exceeded in 4 out of 11 years between 1991 and 2001. The maximum stage was exceeded in 8 out of 11 years. The S333 flow fraction was consistently within the calibration period range.

The fact that stage exceeded the calibration range in 1994 and 1997-1999, even though flow was within the calibration range in those years suggests a change in water management (shift towards maintaining higher water levels at a given flow). Higher stage would promote distribution of inflow P loads over the WCA-3A marsh and reduce transport in the Miami Canal and along the L67 levee. Given the general tendency for P concentrations to decrease with increasing depth at marsh stations, higher water levels may have resulted in lower concentrations at SRS inflows, relative to those which would have occurred without the apparent change in water management.

The high flow and stage conditions in recent years introduce considerable uncertainty in tracking the inflow concentrations relative to the SA limits. When flows exceeding the calibration range are encountered, there are two options for applying the flow-adjustment model that provides the basis for computing the inflow limits: (1) truncate the flow at the maximum base period flow; or (2) extrapolate the model outside of the calibration range. While the SA explicitly states that Option (1) be used in computing the limits, it is useful to examine the sensitivity to this assumption.

Data and interim limits are shown as a function of year in Figure 2 and flow in Figure 3. Observed data are shown in relation to targets and limits computed using each option (truncating vs. extrapolating) in high-flow years. When flows are truncated, the observed concentrations are close to the target in 1994-1996 and exceed the limit in 2000-2001, giving the impression of an increasing trend. When flows are extrapolated, concentrations generally cluster around the limit line and approach the target only in 1997. The point of these comparisons is not to advocate extrapolating the model, but to illustrate sensitivity and uncertainty in interpreting the frequent wet-year data.

Despite the recent drought, stage, flow, and S333 flow fraction were well within the calibration range during 2001. In fact, 2001 was the only year out of the past 9 when all three variables were within the calibration range. Given this, the compliance determination would be more reliable in 2001 than in the previous years. There does not seem to be a basis for interpreting the 2001 excursion as an aberration.

Long-Term Trends

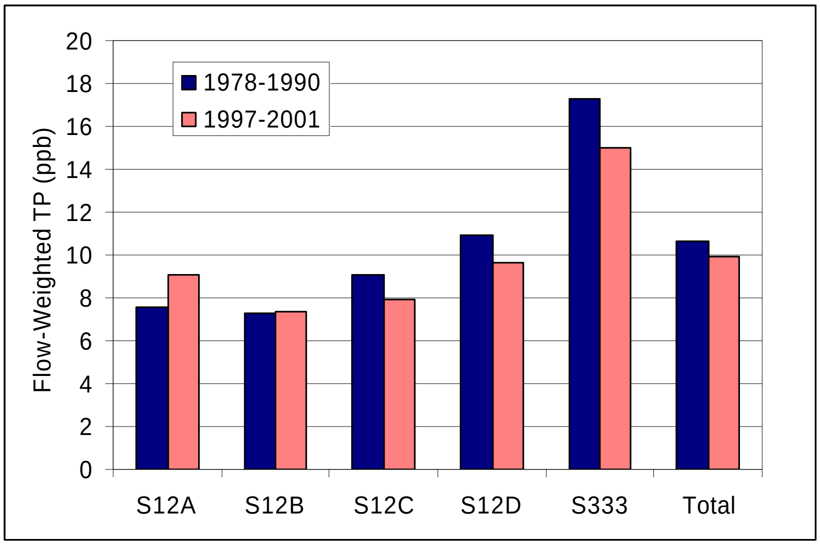
Figure 4 shows the long-term trend in flow-adjusted concentration, computed using the equation listed in Table 1. This statistic tracks the long-term mean by removing effects of year-to-year variations in flow. The yearly data are shown relative to the 1978-1990 trend line inherent in the limit derivation. If the system were in compliance with the interim limits, the flow-adjusted data would be in the 6-11 ppb range that reflects 1978-1979 conditions. The data suggest that the increasing trend apparent in the 1978-1990 data has been arrested in recent years, but concentrations have not decreased sufficiently to expect compliance with the interim limits on a routine basis.

Historically, the S8 pump station on the Miami Canal has been largest source of phosphorus to WCA-3A. Figure 5 shows yearly variations in flow, load, and concentration at this location between 1980 and 2002. Lower P concentrations in 1991-2002 vs. 1982-1990 partially reflect BMP implementation in the EAA. The correlation between load and rainfall has also changed (lower right corner of Figure 5); the load corresponding to a given rainfall was about ~50% lower in 1991-2002, as compared with 1978-1990. S8 concentrations in the past few years have been similar to those measured in 1980-1981, when the ENP SRS inflow P concentrations were also relatively low (Figures 2 & 4). Further significant reductions in concentration and load to WCA-3A are expected when STA-34 is operational.

Despite evidence of significant progress in reducing inflow P concentrations and loads to WCA-3A, there may be a considerable delay between reductions in external loads and reductions in concentration at the S12's and S333. Such a delay could result from P releases from enriched soils in canals and impacted marsh areas within WCA-3A. Continued tracking of loads from S8 and other sources of P to WCA-3A, as well as concentrations at marsh & canal monitoring stations within WCA-3A, will provide a basis for interpreting SRS compliance monitoring data in the upcoming years.

Sensitivity to Flow Distribution

Sensitivity of the flow-weighted-mean inflow concentration to flow distribution across S12's &S333 depends upon the relative magnitudes of concentrations at the individual structures. The following figure compares concentrations at each structure for the model calibration period with values for the last 5 years:



Since P concentrations tend to be higher at S333 than at the S12's, the combined SRS inflow concentration and risk of exceeding the SA limits is sensitive to flow distribution and to changes in water management designed to protect endangered species in the Park (e.g. shift in flow from S12A&B to S333). Despite this shift, the ratio of S333 flow to total flow in recent years has been within the range that occurred during the 1978-1990 model calibration period (Figure 1). Given the above concentrations and starting from an even distribution of flow across all 5 structures, the effect of shifting all of the flow from S12A and S12B to S333 would be to increase the combined inflow concentration by approximately 3 ppb. This change would vary from year to year, depending upon the relative magnitude of the concentrations at each structure. This sensitivity will exist as long as P concentrations at S333 are higher than concentrations at S12A & S12B.

The SA limits were derived to factor out the influence of elevated P concentrations in canal flows (i.e. restore water quality as it existed in 1978-1979 with minimal influence of S333), while accounting for <u>natural</u> hydrologic variations. While changes in water management would not be classified as natural variations, they might be considered by the TOC when interpreting year-to-year variations in the data.

Recommendations

Here are suggested topics for future investigation and/or discussion by the TOC that will support interpretation of historical and future monitoring data from the SRS inflow structures:

1. Compilation of one or more consistent long-term stage records for WCA-3A.

2. Investigation of trends at individual S12 & S333 structures, with and without adjustment for hydrologic factors.

3. Tracking of trends in concentration and load at WCA-3A inflow points and trends in concentration at marsh and intermediate canal stations within WCA-3A.

4. Discussion of how to interpret compliance monitoring results from years when stage exceeded the calibration range.

5. Discussion of whether concentration increases resulting from shifts in flow distribution (i.e. CSSS protection measures) should be considered in determining compliance. The effects on inflow concentration could be estimated in each year by quantifying the actual flow shift and the flow-weighted concentrations at each structure.

6. Discussion of how potential delays in response to loading control measures attributed to P release from impacted areas can be evaluated and considered in interpreting compliance determination during the upcoming years.

7. Further discussion of technical details regarding computation of limits in years when flow is released through S334.

References

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http://www.epa.gov/ost/standards/nutrients/lakes

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Table 1- Derivation of Interim Phosphorus Standards for ENP Shark River Slough Inflows

	Basin	Flow-Weighted-Mean Total P Concentration					
Water	Flow	Observed	Predicted	Flow-Adjusted	De-Trended	50% Target	90% Limit
Year	kac-ft/yr	ppb	ppb	ppb	ppb	ppb	ppb
78	522.8	6.7	8.4	6.7	7.0	8.4	11.7
79	407.0	9.8	9.6	9.2	9.5	9.0	12.3
80	649.2	10.6	9.0	11.2	9.7	9.6	11.1
81	291.7	12.4	11.3	11.4	11.0	10.2	12.9
82	861.3	8.4	9.2	10.0	6.3	10.8	10.1
83	1061.3	7.0	8.9	9.5	4.4	11.4	9.4
84	842.8	12.0	10.5	13.4	8.7	12.0	10.2
87	276.6	15.9	14.9	14.8	10.9	13.8	13.0
88	585.5	15.6	14.1	15.9	10.0	14.4	11.4
89	116.9	13.5	16.9	11.6	7.3	15.0	14.0
90	148.2	18.1	17.3	16.3	11.2	15.6	13.8
Mean	523.9	11.8	11.8	11.8	8.7	8.7	11.8

Variables:

C = Observed TP (ppb)
T = Water Year (October-September)
b_1, b_2 = Regression Slopes
m = subscript denoting mean value
Q = Observed Flow (kac-ft/yr)
E = Random Error (ppb)
SE = Regression Standard Error of Estimate (ppb)

Regression Model:

$$C = C_m + b_1 (T - T_m) + b_2 (Q - Q_m) + E$$

$$= 11.8 + 0.5932 (T - 83.7) - 0.00465 (Q - 523.9) + E$$

Regression Results:

$R^2 = 0.80$ | SE = 1.873 ppb | C_m = 11.8 ppb | T_m = 83.7
Q_m = 523.9 kac-ft/yr | b_1 = 0.5932 | $Var(b_1)$ = 0.02366 | b_2 = -0.00465
$Var(b_2)$ = -0.0046 | $Cov(b_1,b_2)$ = 0.00013 | $t_{\alpha,dof}$ = 1.397 | n = 11

C_Q = Flow-Adjusted TP $= C + b_2 (Q_m - Q) = C - 0.00465 (523.9 - Q)$

C_T = De-Trended TP [adjusted to T_o = 78.5] $= C + b_1 (T_o - T) = C + 0.5932 (78.5 - T)$

Target $= C_m + b_1 (78.5 - T_m) + b_2 (Q - Q_m) = 11.16 - 0.00465 Q$

Limit = Target + S $t_{\alpha,dof}$ = 11.16 - 0.00465 Q + 1.397 S

$$S = [SE^2 (1 + 1/n) + Var(b_1) (T_o - T_m)^2 + Var(b_2) (Q_c - Q_m)^2 + 2 Cov(b_1,b_2) (T_o - T_m)(Q_c - Q_m)]^{0.5}$$

$$= [6.377 - 0.00591 Q + 0.00000436 Q^2]^{0.5}$$

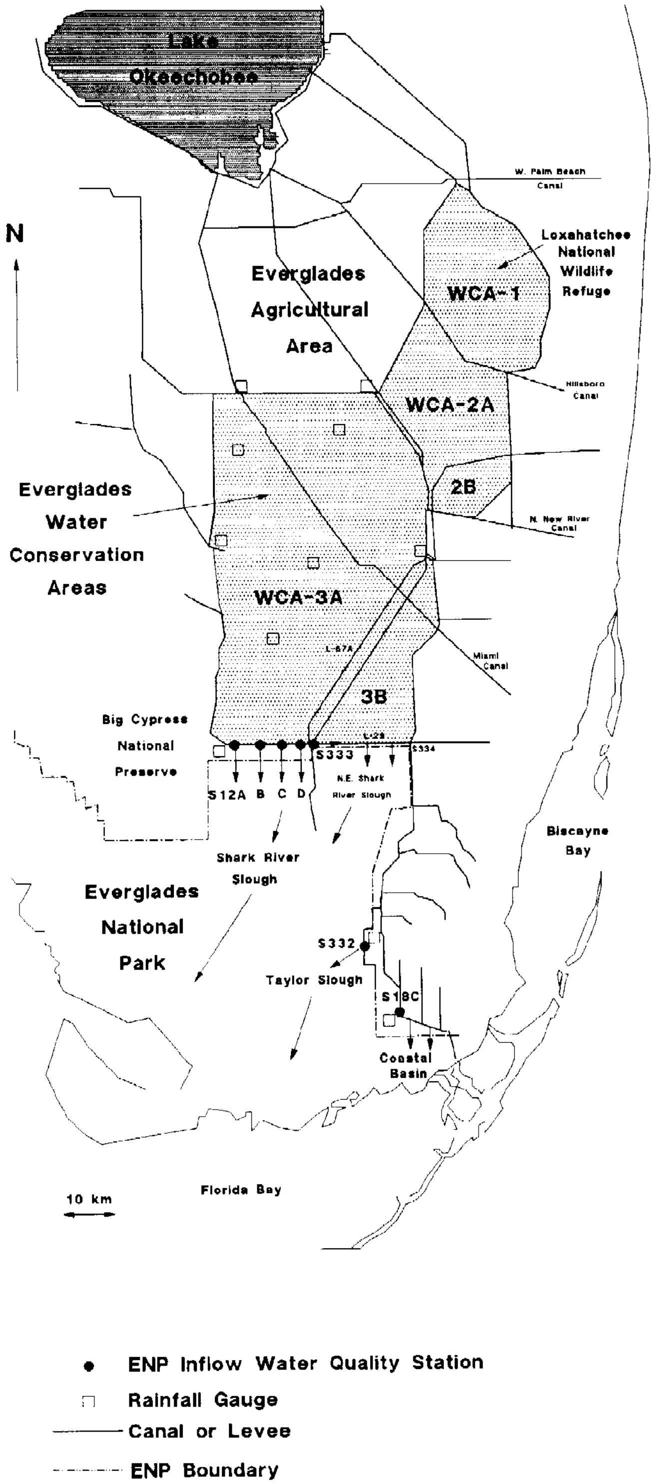


Figure 1. Station Map.

watersheds: Shark River Slough (S12A, S12B, S12C, S12D, and S333), Taylor Slough (S332), and Coastal (S18C). The period of record is December 1977-September 1989 for Shark River Slough and October 1983-September 1989 for Taylor Slough and Coastal stations.

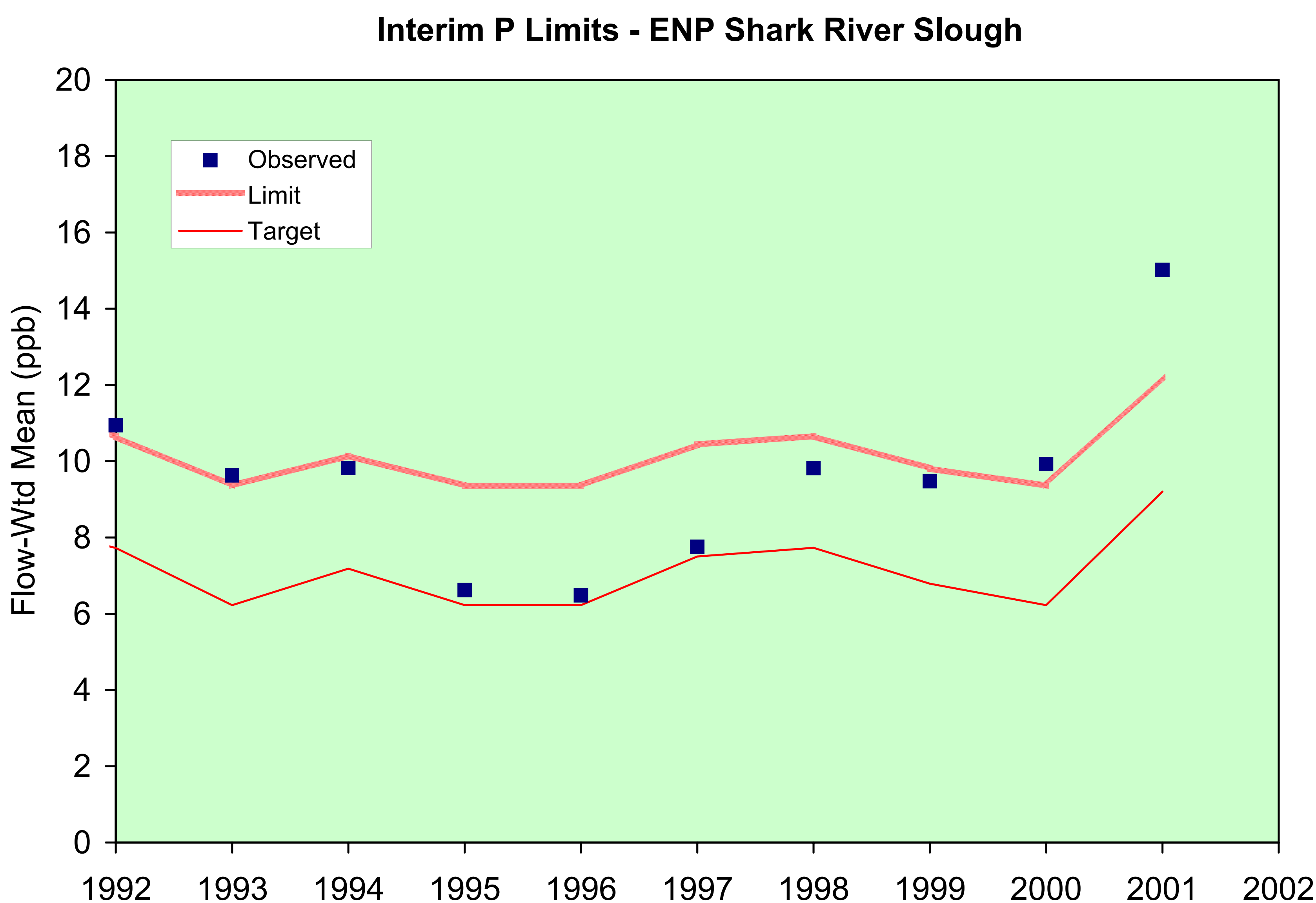
Two composite time series (S12T and S12.334) have been constructed by calculating flow-weighted-mean concentrations across structures in Shark River Slough on each sampling date. Station S12T reflects total discharge Shark River Slough west of L67 (= S12A + S12B + S12C + S12D). Station S12.334 reflects total discharge to Shark River Slough, including the Northeast portion. These composite series have been constructed to reflect total releases to Shark River Slough and to minimize effects of shifts in flow distribution across the individual outlet structures during the monitoring period (SFWMD, 1990; Walker, 1990).

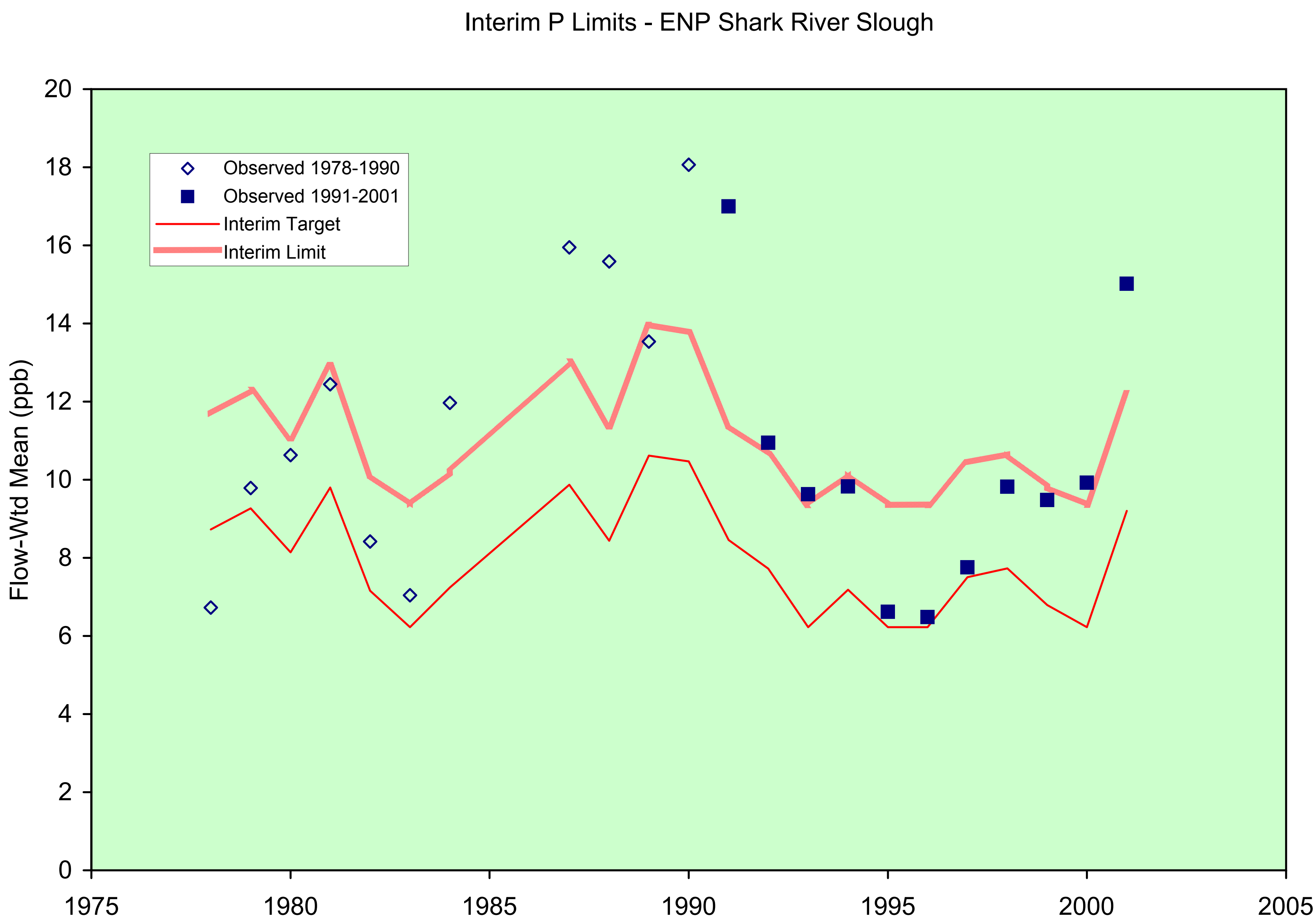
Detection of water quality trends is often complicated by hydrologic variations (Smith *et al.,* 1982). Daily flow, water elevation, and rainfall measurements have been compiled for studying correlations between hydrology and water quality (SFWMD, 1988; USGS, 1989). A spatially-averaged rainfall time series for WCA-3A has been constructed by averaging data from nine gauges in and around the reservoir (Figure 1). Mean daily water surface elevation measured by the U.S. Geological Survey upstream of S12C in WCA-3A provides an additional hydrologic variable for use in analyzing concentration data at inflows to Shark River Slough.

The analysis considers 20 water quality components, including nutrients, field measurements (dissolved oxygen, temperature, pH, conductivity), inorganic species, and optical properties (color, turbidity). Table 1 summarizes the number of observations and median concentration for each station and water quality variable. Values reported below the detection limit have been set equal to the detection limit minus a small concentration increment (0.0001 mg/liter). In this way, such values can be distinguished from values equal to the detection limit (Hirsch *et al.,* 1982). Since the trend test is based upon ranks, the precise magnitude of the concentration increment does not influence computed significance levels. The percentage of total phosphorus values reported below detection limits ranges from 1 percent to 20 percent for the individual sampling stations.

STATISTICAL METHODS

The trend analysis methodology (Figure 2) employs the seasonal Kendall test (Hirsch *et al.,* 1982; Hirsch


Interim P Limits - ENP Shark River Slough
Flow-Wtd Mean (ppb)
Observed
Limit
Target
0
2
4
6
8
10
12
14
16
18
20
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002


Interim P Limits - ENP Shark River Slough
Flow-Wtd Mean (ppb)
Observed 1978-1990
Observed 1991-2001
Interim Target
Interim Limit
0
2
4
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1975
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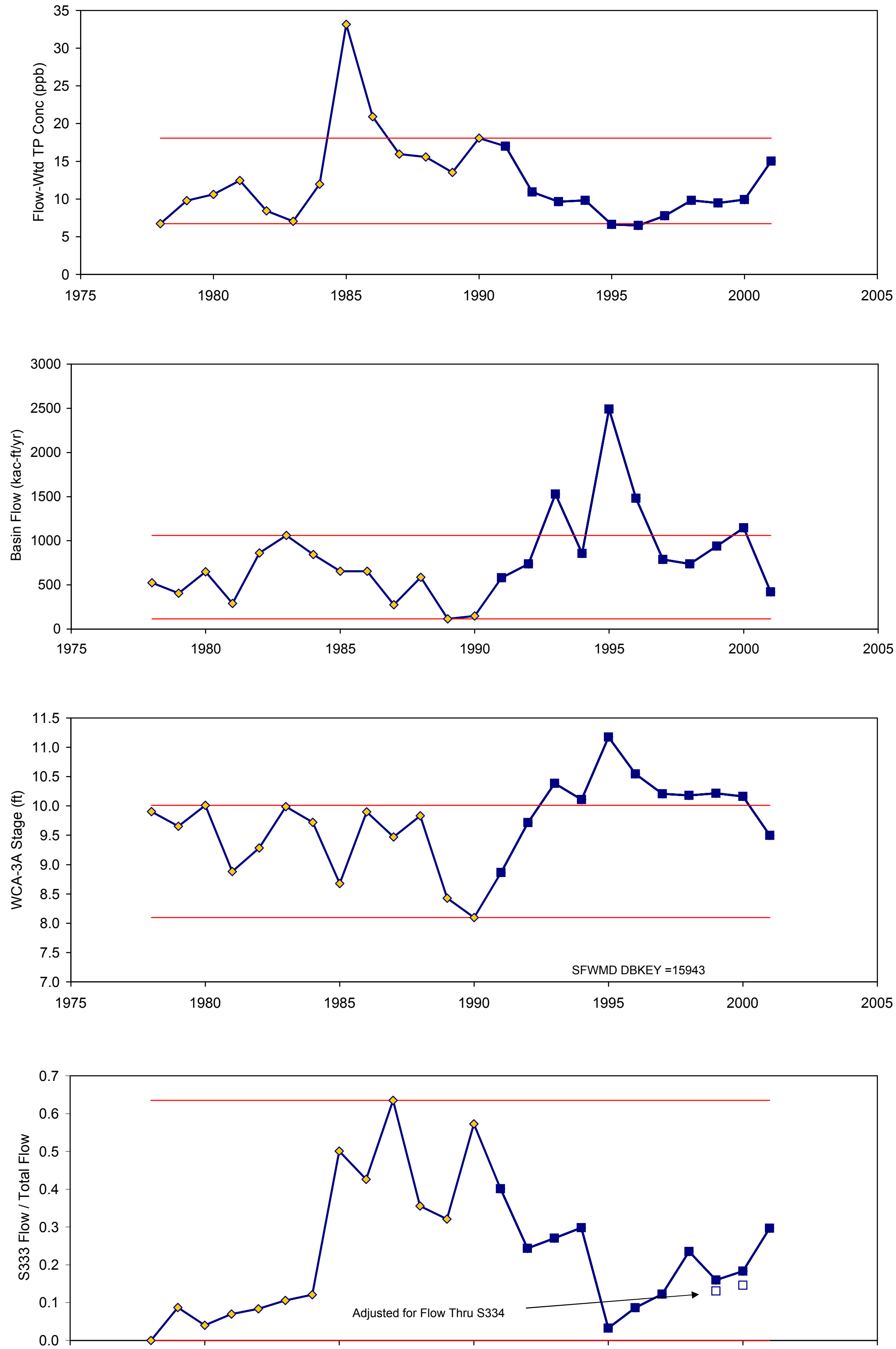
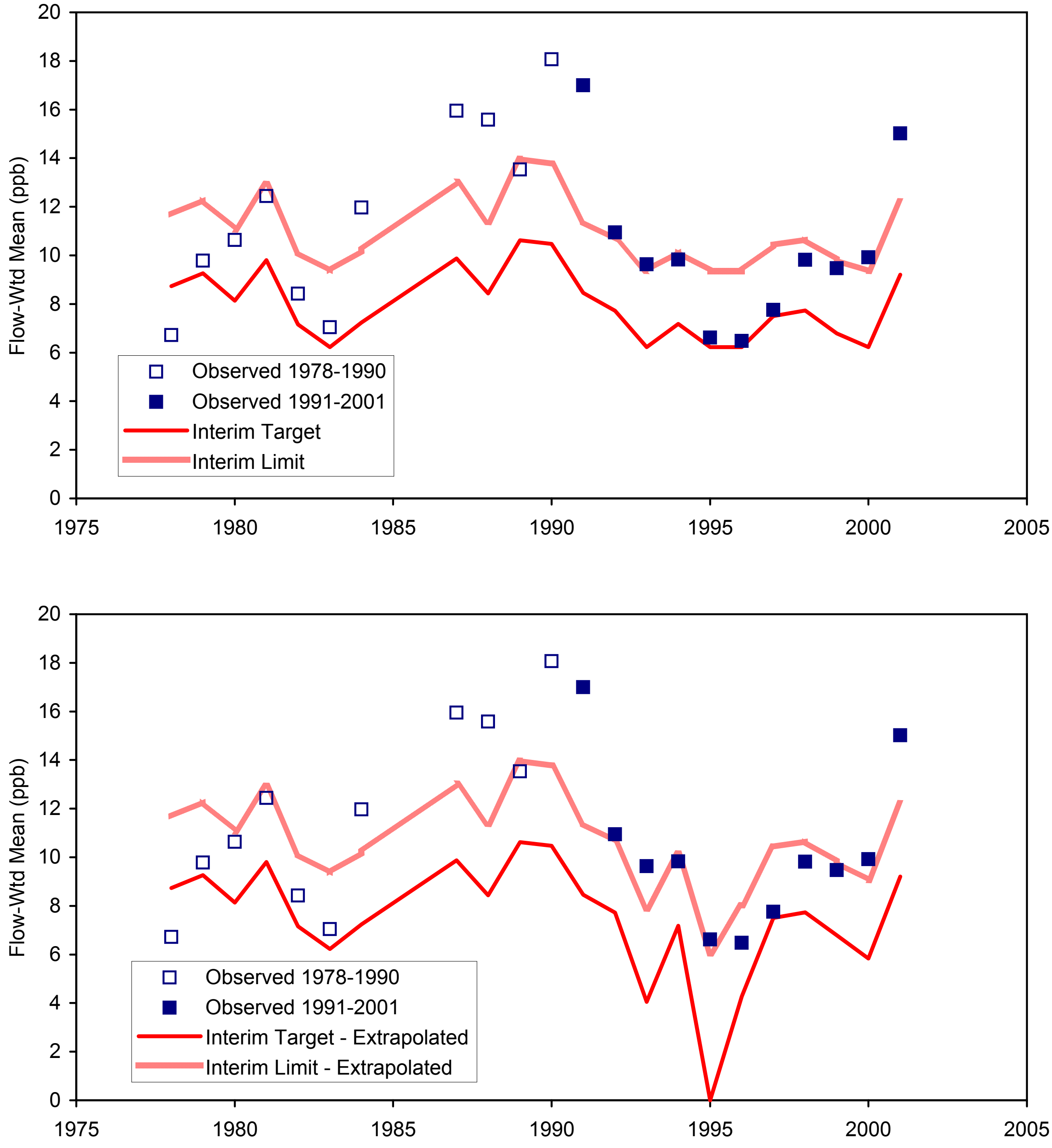
2005

Figure 1 **Concentration & Hydrologic Time Series**



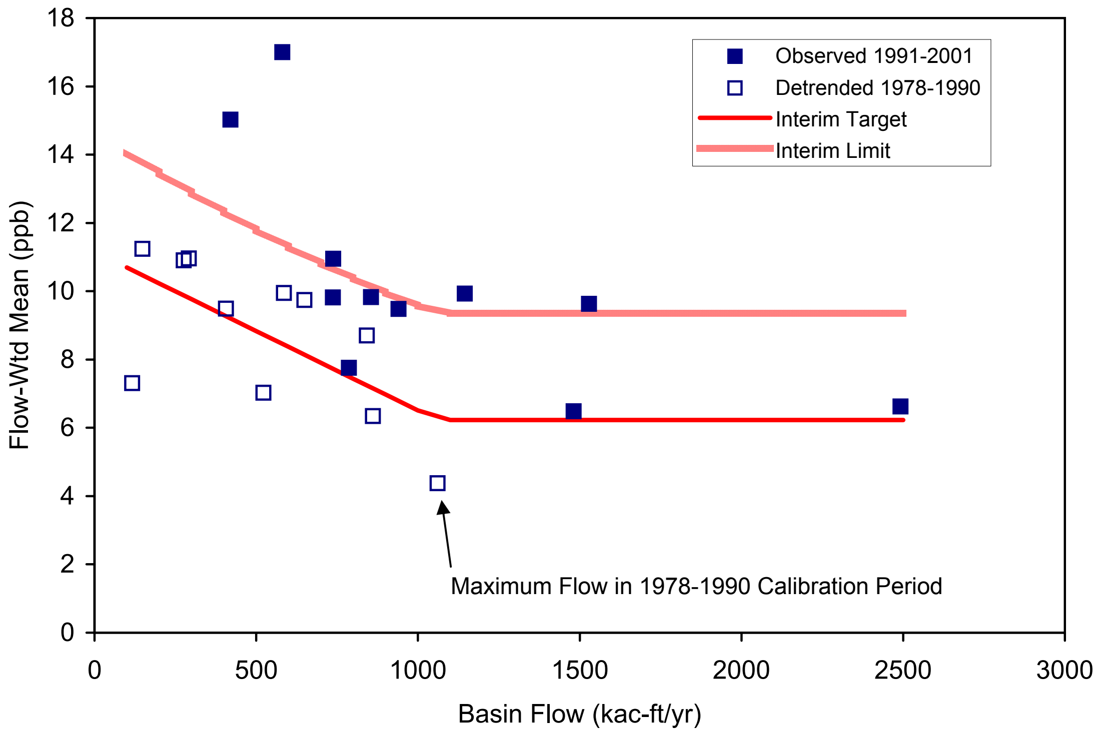
Horizontal Lines= Range During Period Used to Calibrate Limit Equations (1978-1990, excluding 1985-1986)

Figure 2 **Interim Compliance Limit vs. Year**



Top Panel Flow used to compute target & limit is constrained to 1978-1990 maximum.
Bottom Panel Flow is not constrained (extrapolates model beyond calibration range).

Figure 3 **Interim Compliance Limit vs. Flow**



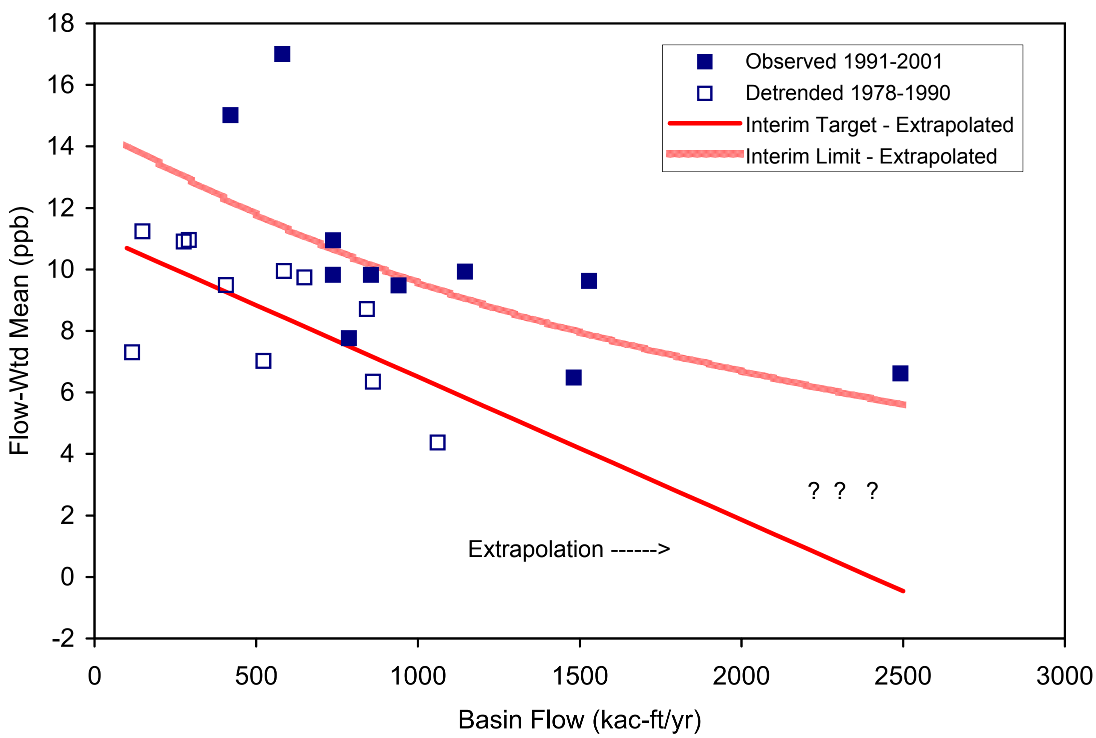
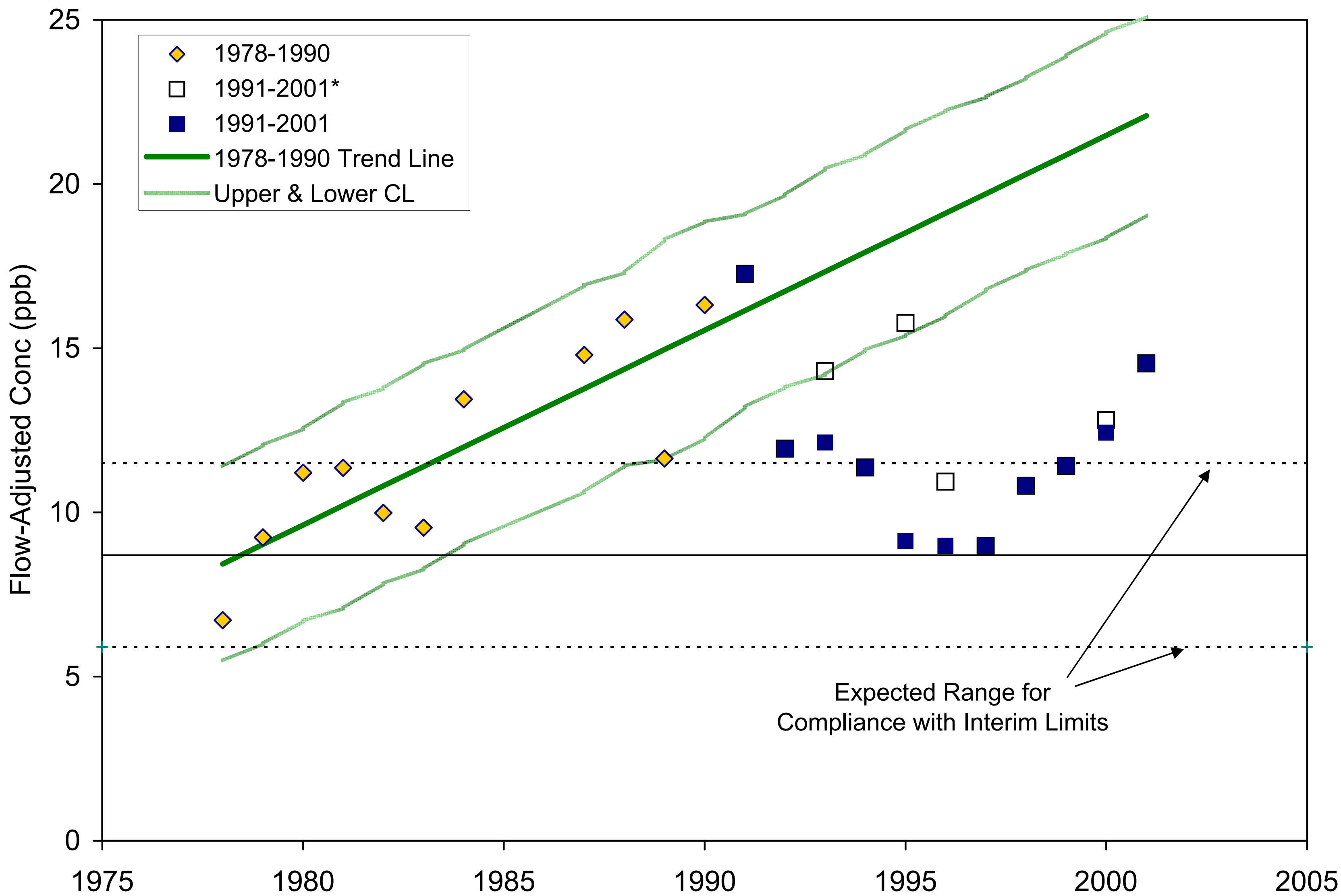


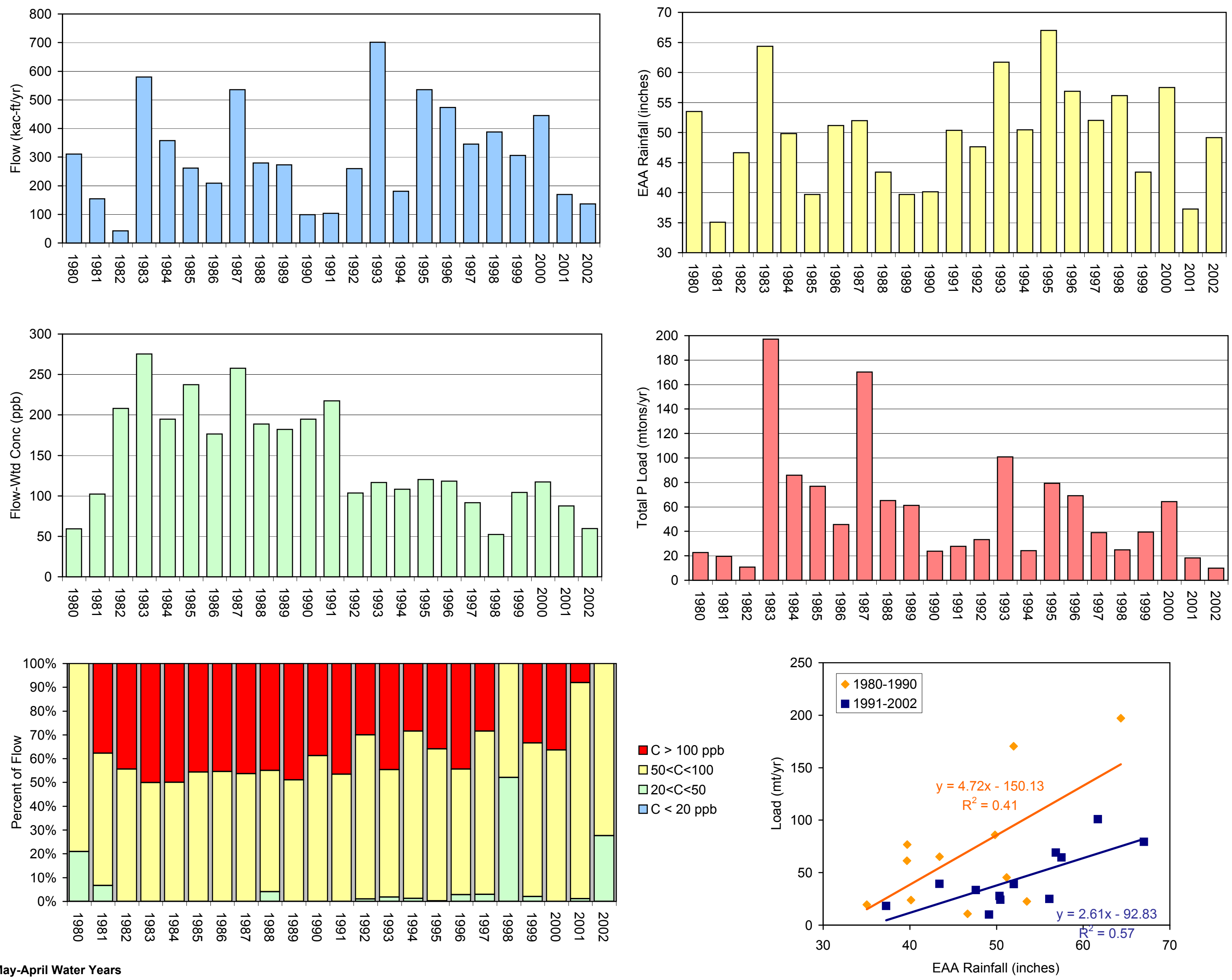
Figure 4 Long-Term Trends in Flow-Adjusted Concentration



* Flow-Adjusted Concentration, Allowing Extrapolation of Model Beyond Calibration Range

Figure 5 Yearly Flows & Phosphorus Loads

Outflow from Miami Canal to WCA-3A @ S8



May-April Water Years