Development of Long-Term Phosphorus Limits For Shark River Slough Inflows

Prepared for US Dept. of the Interior

William W. Walker, Jr., Ph.D.

Discussion at TOC Sub-Team Meeting on
Appendix A of the Settlement Agreement

December 10, 2013

Development of Long-Term Phosphorus Limits For Shark River Slough Inflows

- Settlement Agreement
- Process
- Data Review
- Equations
- Recent Data

Settlement Agreement - 1992

- Federal (DOI, FWS) vs. State (SFWMD, DER->DEP)
  - Acknowledge Significant Impacts of Nutrient Enrichment
  - Eliminate Imbalance in Flora & Fauna
  - Restore & Protect Water Quality
  - Restore Hydrology (Volume, Timing, Distribution, etc.)
  - Develop Numerical Class III P Criterion (~ 10 ppb ?)
  - Adopt Long-Term Limits as OFW standards for Refuge & Park
  - Establish Technical Oversight Committee
  - Research & Monitoring
  - Etc…
- Interim & Longterm Numerical P Limits for Refuge & Park
- Control Program (BMPs, STAs, etc.) and Schedule
- Structure for Implementation

Settlement Agreement – 1992

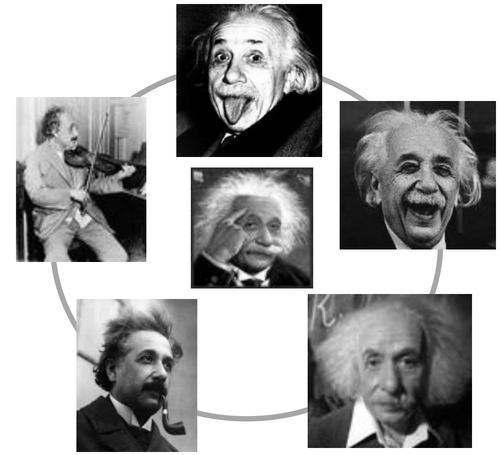
- Federal (DOI, FWS) vs. State (SFWMD, DER->DEP)

- Interim & Long-Term Phosphorus Limits For Park & Refuge
  - Developed by ~10+ tech reps from FWS, ENP, DER, SFWMD, consultants
  - Best available data (SFWMD WQ, COE/SFWMD Flow & Stage)
  - Interim (~1978-1979 data, ~anti-degradation, existing impacts embedded)
  - Longterm (~1978-1979 subset, ~less-impacted, ~Class III surrogate)
  - Consider baseline, trends, hydrologic & other sources of variability
  - Subject to TOC interpretation (error, extraordinary natural phenomena..)

- Control Program (BMPs, STAs, etc.)
  - Adaptive framework for achieving goals
  - Phase I (50 ppb), Tech Based --> Interim Limits by ~2002
  - Phase II, TBD Enhanced Tech -> Long-term Limits & Class III by ~2006

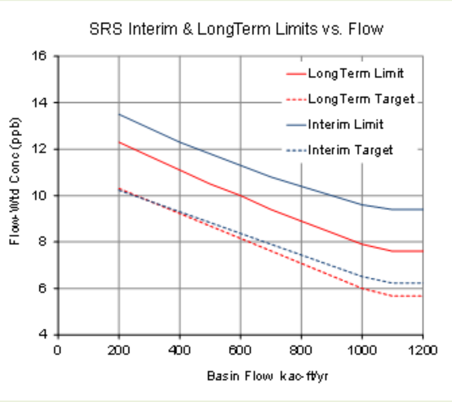
- Structure for Implementation
  - TOC (data analysis & interpretation, error/extraordinary, research etc.)
  - Principals (broader interpretations & recommendations, all things considered)
  - Legal (ultimate decision on compliance & remedies if necessary)

Technical Team - Culprits & Process



- Technical Team Met for Several Months
  - DER (Nearhoof, Harvey, ...)
  - SFWMD (Macvikar, Federico, Shi, Robson...)
  - US (Maffei, Scheidt, Soukup, Walker...)
- Factors Considered in Developing Limits
  - Restoration objectives
  - Best available data from structures & marsh
  - Historical hydrology, concentrations, & trends
  - Spatial distribution of impacted areas / gradients
  - Literature on eutrophication criteria ~10 ppb?
  - Research in Park & Everglades marsh
  - Input from Legal/Policy Team (CWA, OFW, ONRW, Class III narrative, …)
  - Account for trends, hydrologic, seasonal, & other sources of variability
  - Unavoidable risks and tradeoffs of Type I vs. Type II error
  - Monitoring requirements
  - Parallel technical analysis to replicate results

- Several Iterations with Legal/Policy Team
- Binding agreement signed by agency officials & judge



"Fail-Safe"

Interpretations of compliance results by TOC & principles are critical. An exceedance is only one factor driving the "appropriate action".

"An exceedance occurs if the flow-weighted-mean concentration for the water year ending September 30th is greater than the 10% rejection level of the computed limit (see Attachments).

Based upon review of trends for flow-weighted means, trends for the frequencies of samples exceeding 10 ppb, and other information found relevant by the panel, the TOC members will forward their opinions and recommendations to their respective agencies for appropriate action.

An exceedance will constitute a violation unless the TOC determines there is substantial evidence that it is due to error or extraordinary natural phenomena. A violation of a long term limit shall constitute a violation of this Agreement and of the OFW water quality standard for Park areas immediately downstream of the inflow structures."

SA- WATER QUANTITY REQUIREMENTS

9. “Quantity, distribution and timing of water flow to the Park and Refuge must b sufficient for maintaining and restoring the full abundance and diversity of the native floral and faunal communities throughout the Park and Refuge. The Parties shall take all actions within their authority necessary to provide adequate flows to meet the water quantity, distribution, and timing needs of the Park and the Refuge. The District shall implement mitigation measures to offset flow reductions to the EPA resulting from efforts to improve the water quality in the EPA. Additionally, the Parties through the TOC shall jointly develop specific elements of these actions as part of a basin-wide Everglades ecosystem restoration plan. Nothing in this Agreement shall limit or prejudice any rights of the Park or Refuge under State or Federal law to obtain greater or more specific water quantity.”

APPENDIX A

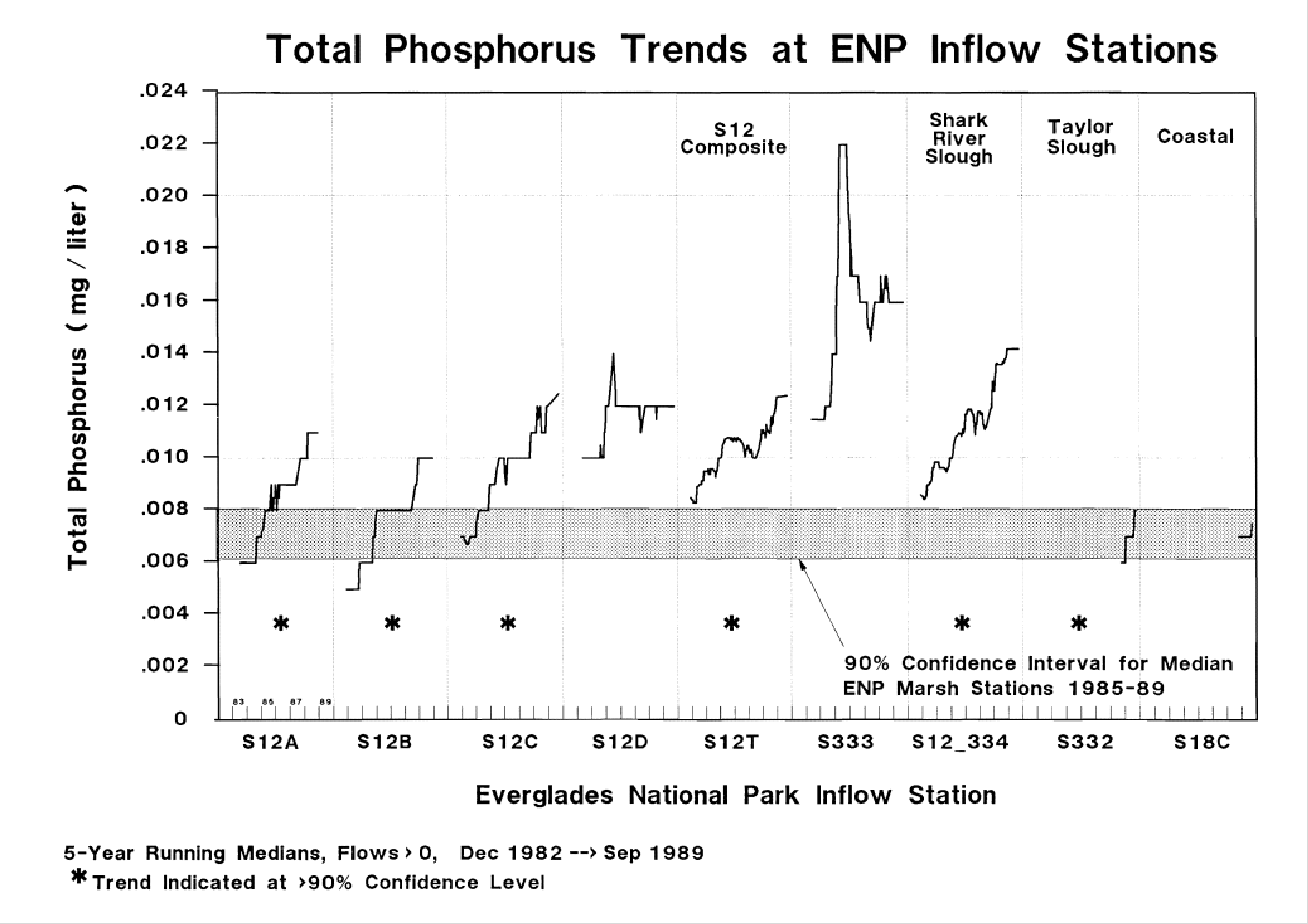
P1. “In each basin, long term discharge limits are the limits necessary to meet the OFW water quality criteria as measured at the structures discharging into the Park. These limits will also apply to areas immediately downstream in the Park and will be used to determine compliance. The adequacy of these OFW criteria to meet the State water quality standard Class III criteria (to prevent an imbalance of flora and fauna) will be verified by long term monitoring and research.”

OFW Language

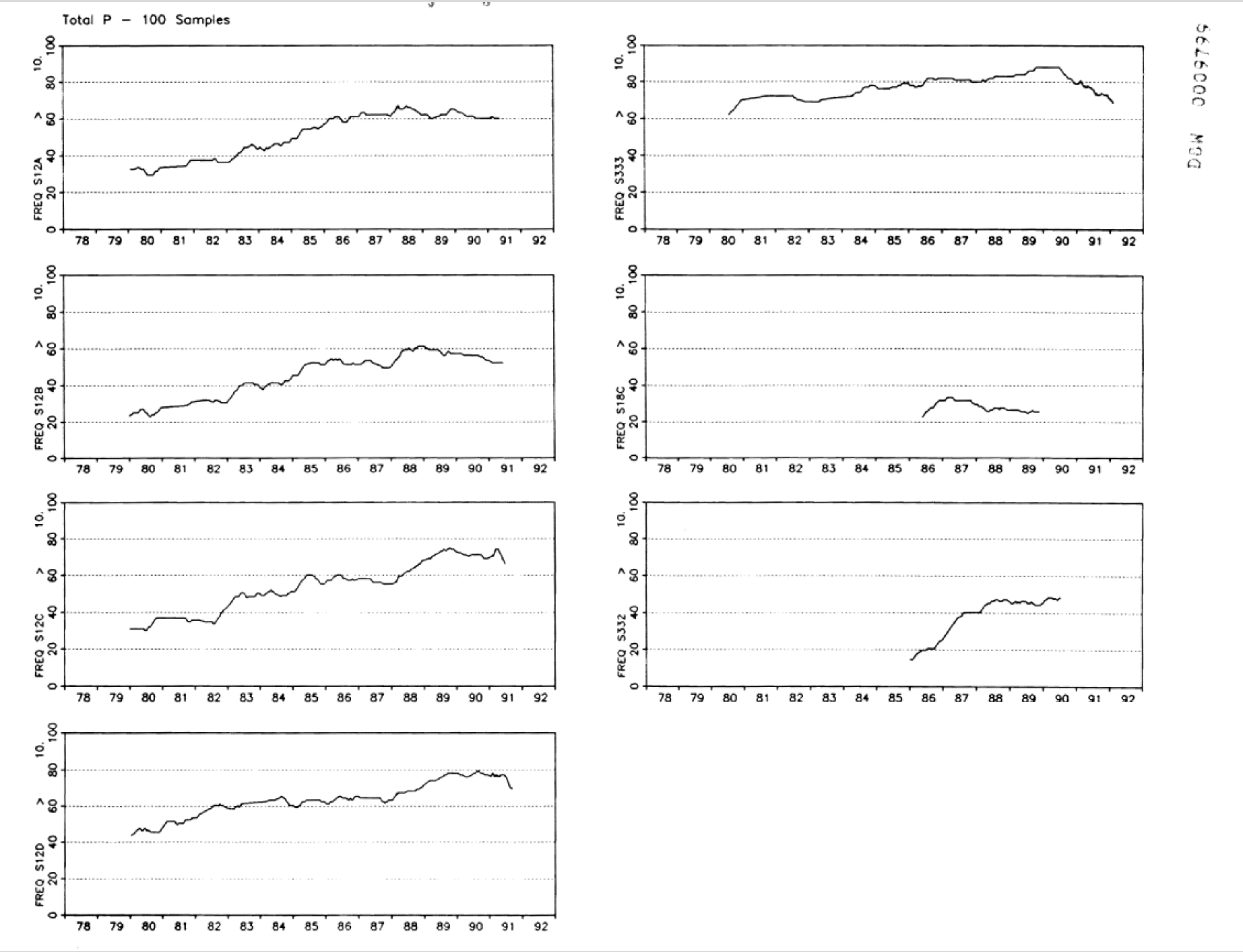
- “The existing ambient water quality within OFW will not be lowered as a result of the proposed activity or discharge....”
- “...“existing ambient water quality” shall mean (based on the best scientific information available) the better water quality of either (1) that which could reasonably be expected to have existed for the baseline year of an Outstanding Florida Water designation (2) that which existed during the year prior to the date of a permit application”
- “It shall include daily, seasonal, and other cyclic fluctuations, taking into consideration the effects of allowable discharges for which Department permits were issued or applications for such permits were filed and complete on the effective date of designation...”

Preliminary Data Analyses
Discovered in
Soggy Basement File Boxes
Circa 1989-1992

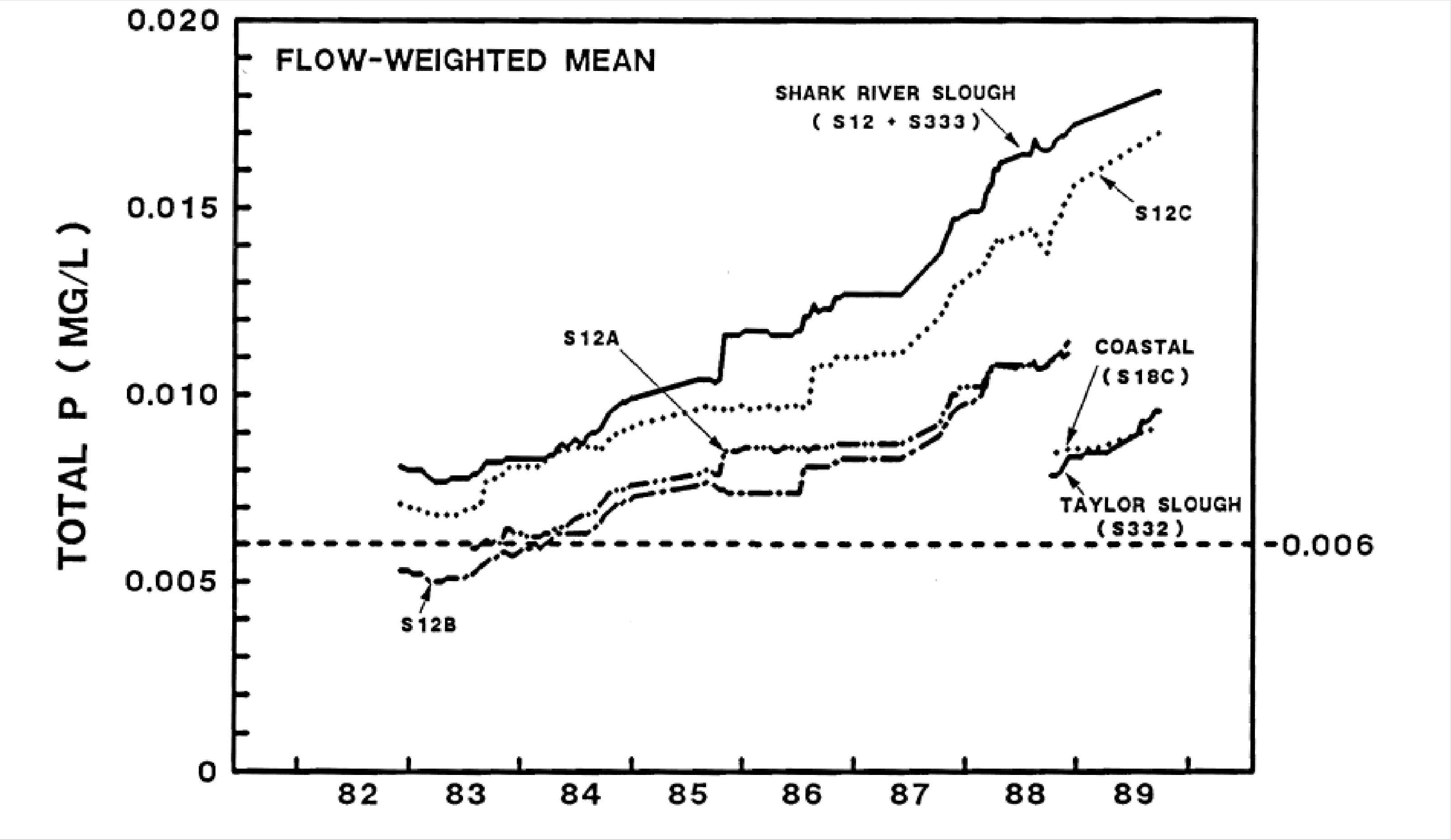
5-Yr Running Median TP Concs. at ENP Inflow Sites



100-Sample Rolling Frequencies TP > 10 ppb

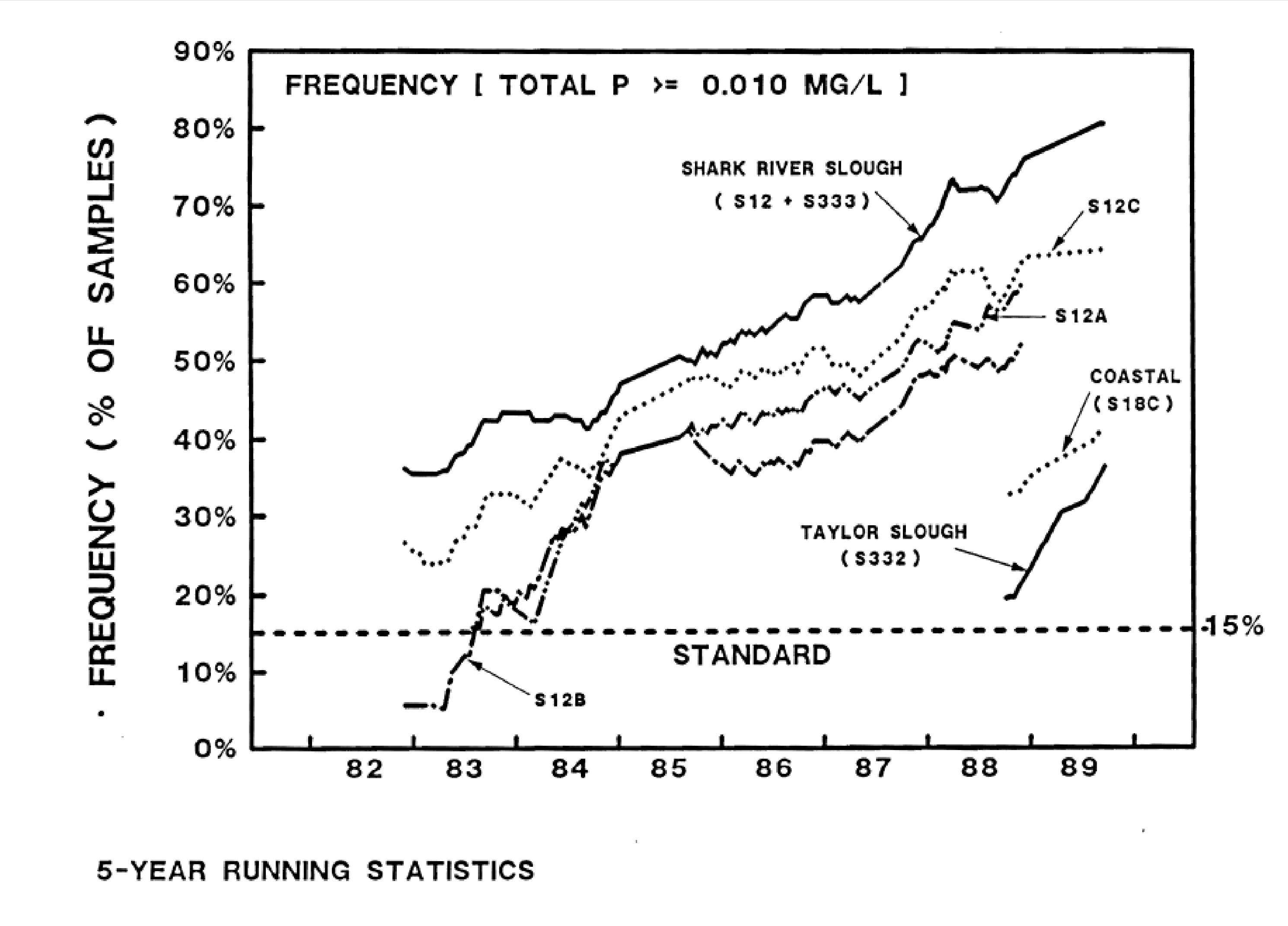


5-Yr Rolling Flow-Weighted Means



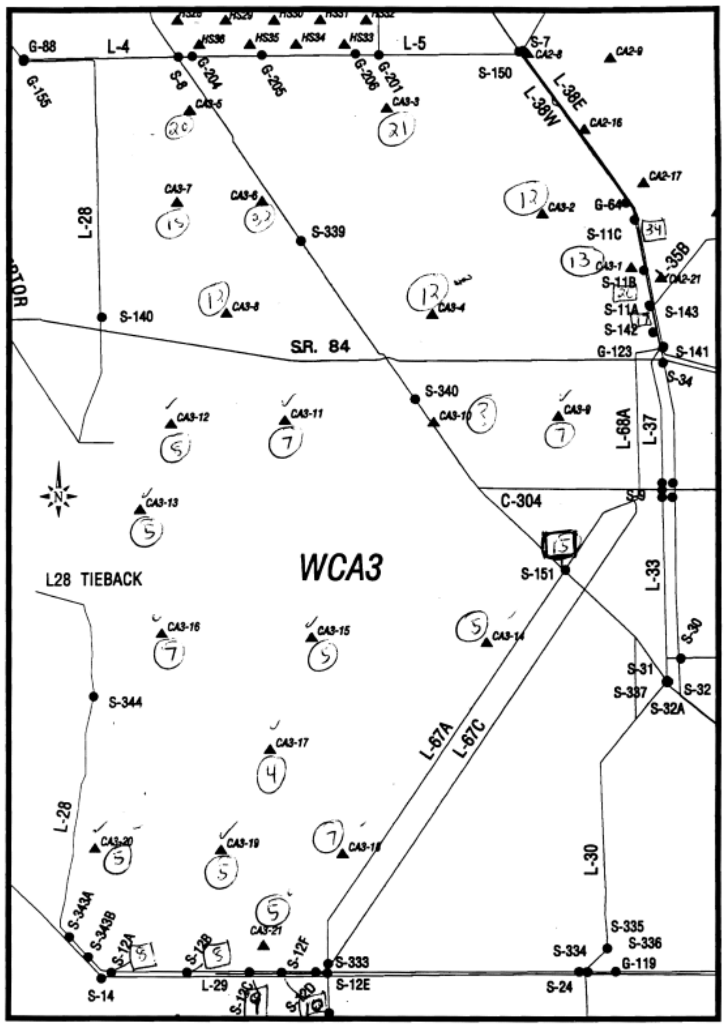
5-YEAR RUNNING STATISTICS

5-Yr Rolling Frequency TP > 10 ppb

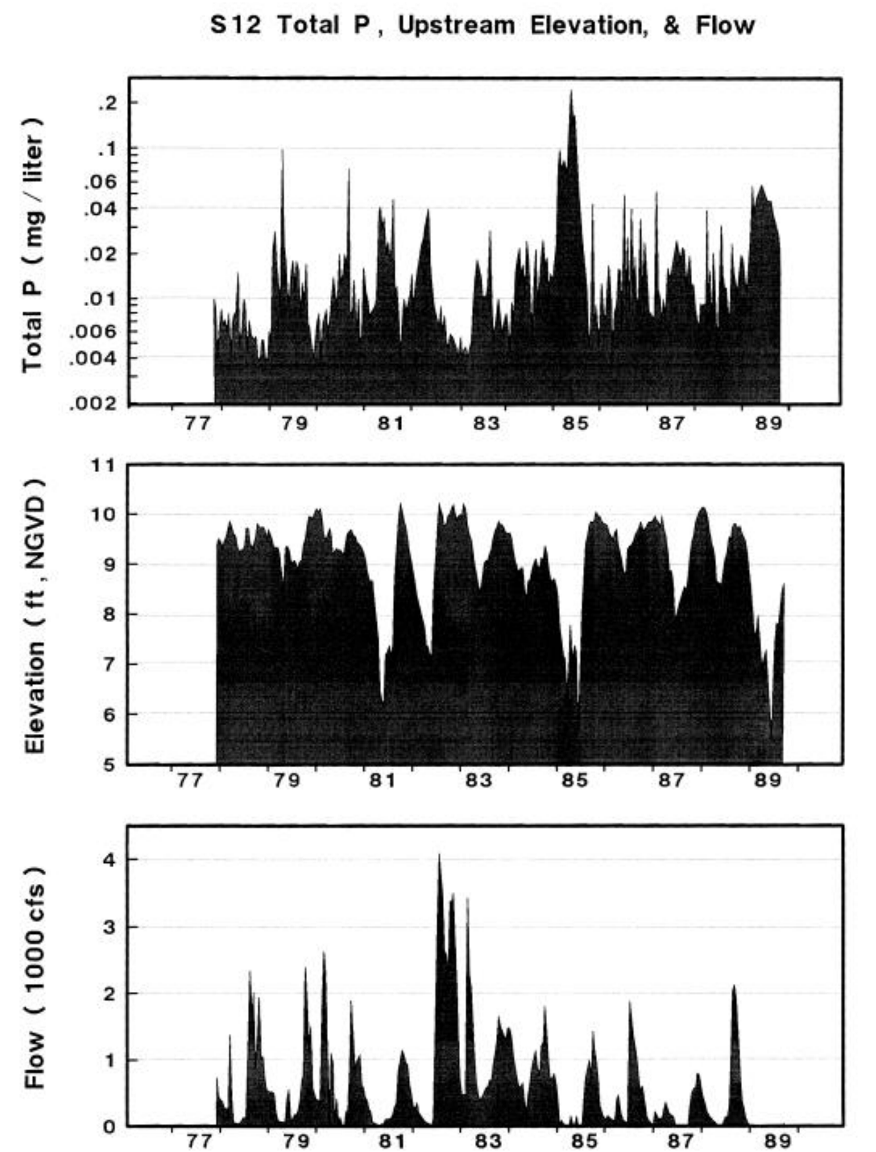


Examined WCA-3A Marsh Data
Geo Means, 1978-1982, SFWMD Report

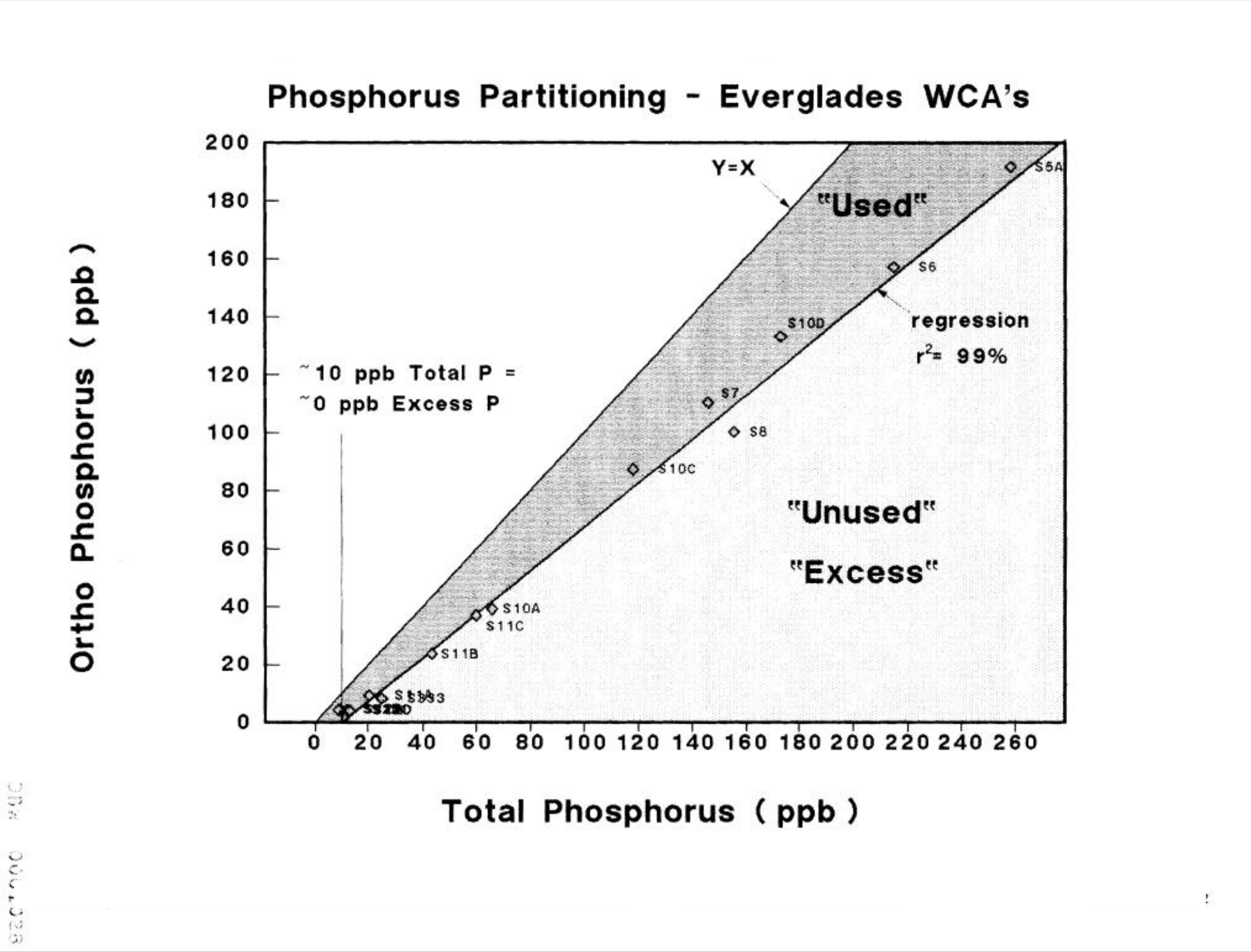
Figure 2-3 Sites monitored by the SFWMD during 1978 -1982 in WCA-3a.



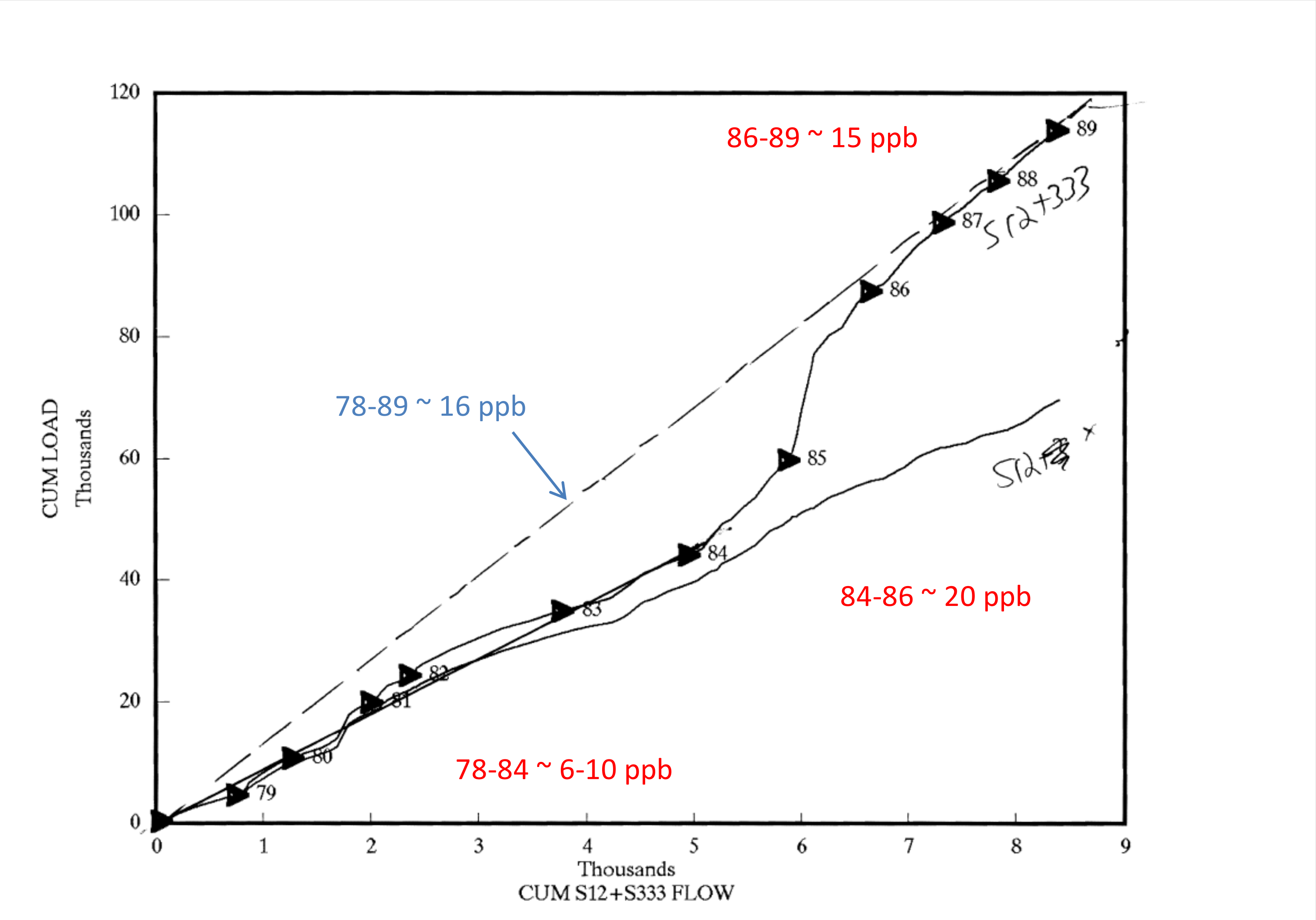
WATER QUALITY MONITORING STATIONS
WATER CONSERVATION AREA 3


S12 Total P, Upstream Elevation, & Flow
Total P (mg / liter)
.2
.1
.06
.04
.02
.01
.006
.004
.002
77
79
81
83
85
87
89
Elevation (ft , NGVD)
11
10
9
8
7
6
5
77
79
81
83
85
87
89
Flow (1000 cfs)
4
3
2
1
0
77
79
81
83
85
87
89

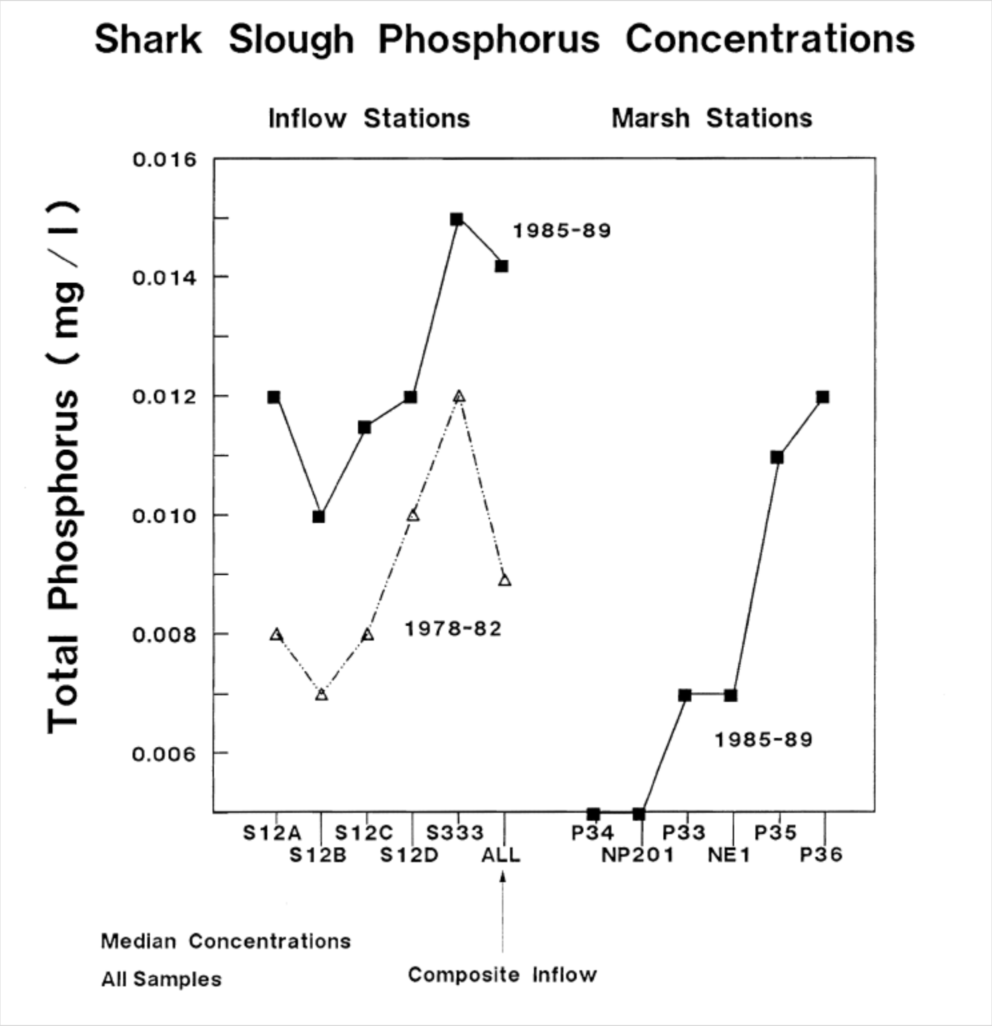
SRP & TP Gradients in WCAs

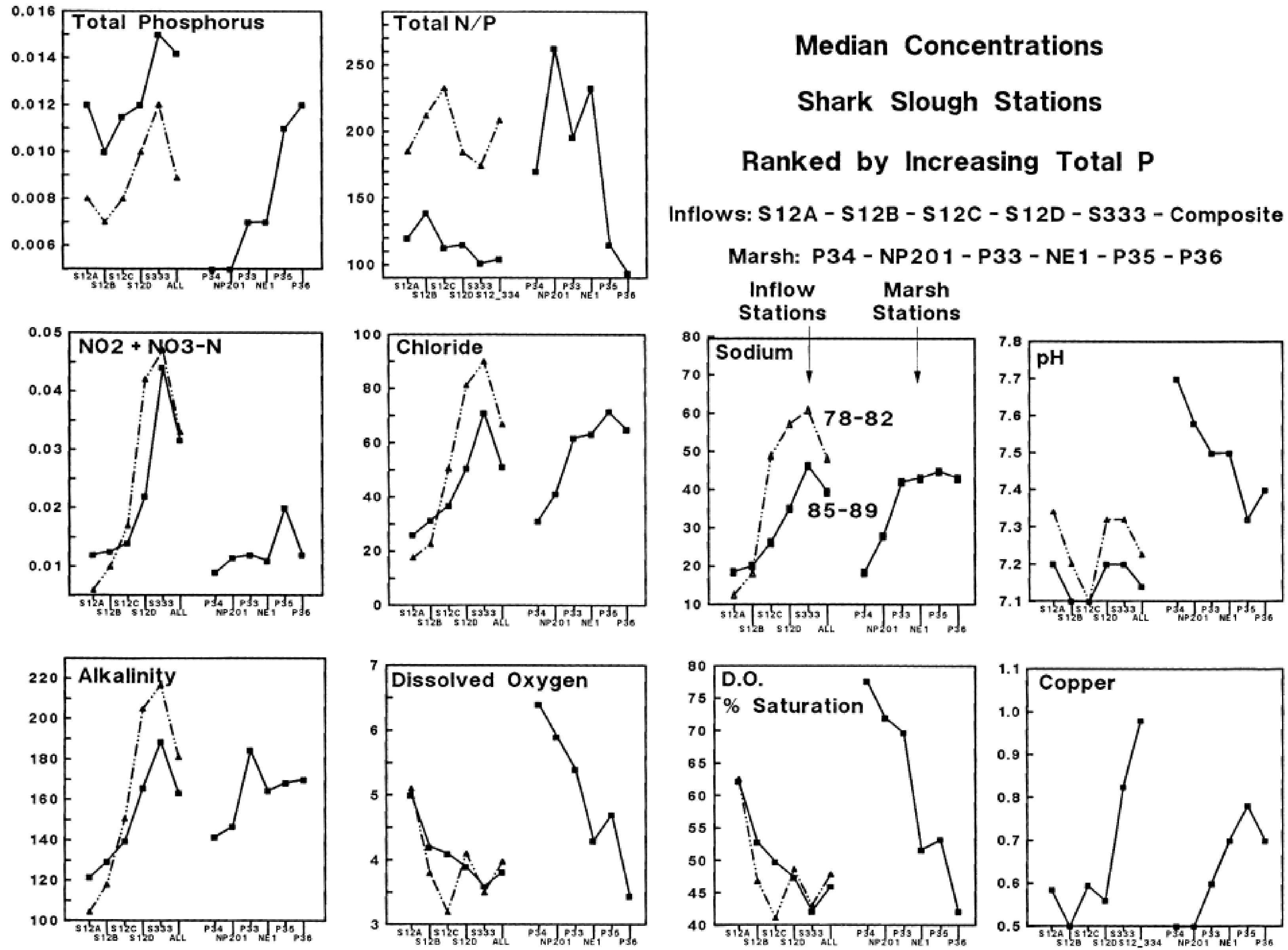


Double Mass Curve - Cum Load vs. Cum Flow
1978-1989, FWM Conc. = Load / Flow

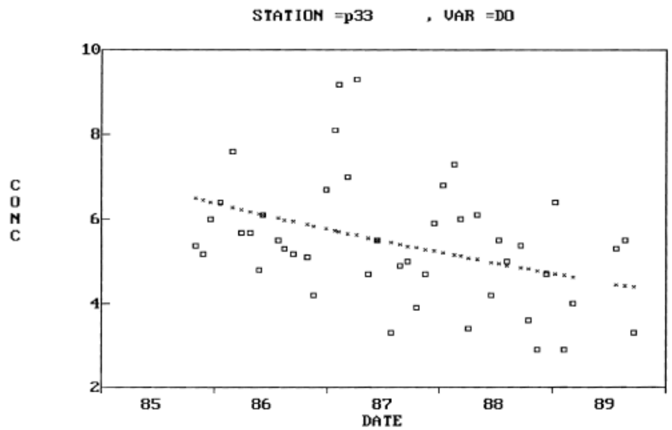


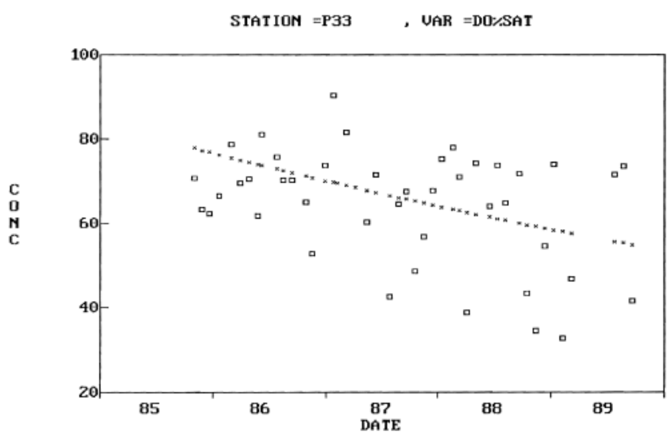
Structure vs. Marsh TP




Median Concentrations
Shark Slough Stations
Ranked by Increasing Total P
Inflows: S12A - S12B - S12C - S12D - S333 - Composite
Marsh: P34 - NP201 - P33 - NE1 - P35 - P36
Inflow Stations
Marsh Stations
Total Phosphorus
Total N/P
NO2 + NO3-N
Chloride
Sodium
78-82
85-89
pH
Alkalinity
Dissolved Oxygen
D.O. % Saturation
Copper
S12A S12B S12C S12D S333 ALL
S12_334
P34 NP201 P33 NE1 P35 P36

P33 - Dissolved Oxygen (mg/l) & % Saturation





Rank Correlations with Total P
Median Values – ENP Marsh Stations

Group	All		Shark Sl.	
Stations	9		6	
Total P	1.00		1.00	
Total N/P	−0.74		−0.70	
Total N	0.26		0.49	
Kjeldahl N	0.19		0.37	
Organic N	0.26		0.50	
NO2+NO3–N	0.57		0.81	*
Ammonia N	0.08		0.42	
pH	−0.15		−0.89	**
Alkalinity	0.71	**	0.77	
Conductivity	0.34		0.65	
Chloride	0.36		0.90	**
Sulfate	−0.31		0.10	
Calcium	0.31		0.50	
Magnesium	0.21		0.57	
Potassium	0.12		0.50	
Sodium	0.35		0.87	*
Color	0.48		0.57	
Turbidity	0.30		0.50	
Temperature	−0.52		−0.77	
Dis. Oxygen	−0.71	**	−0.90	**
D.O. % Sat.	−0.71	**	−0.90	**
Copper	0.41		0.86	*

Period of Record: Oct 85 – Sep 89
All Samples

** p < .05   * p < .10

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DESIGN BASIS FOR EVERGLADES STORMWATER TREATMENT AREAS[1]

William W. Walker, Jr.[2]

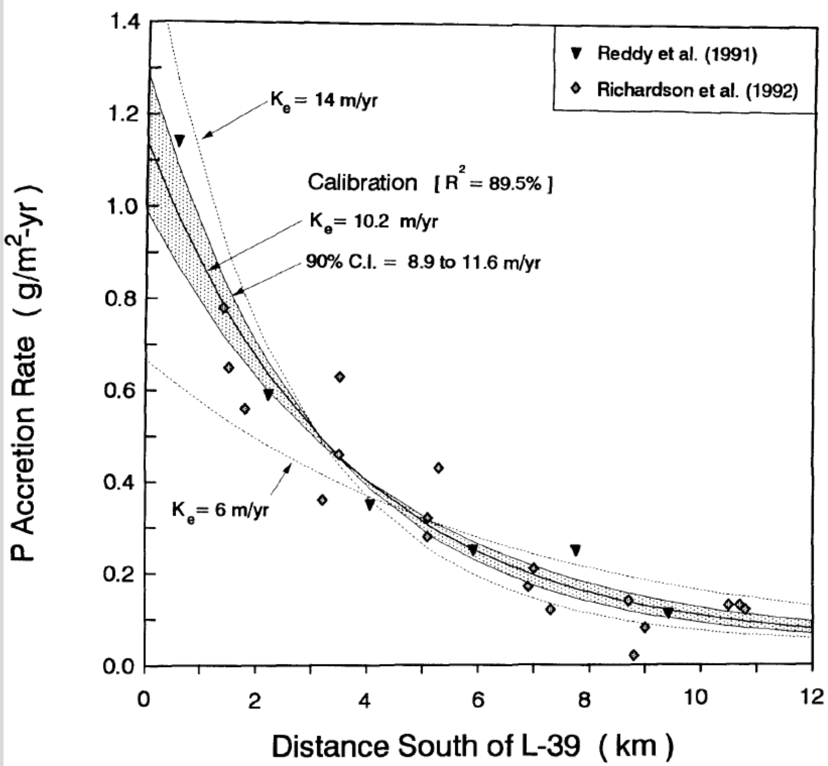


Figure 4. Observed and Predicted Phosphorus Accretion Rates. Symbols depict measured, 26-year-average accretion rates. Solid line depicts model prediction with the calibrated setting rate (10.2 m/yr). Shaded area depicts model prediction for the 90 percent confidence interval in settling rate (8.9 to 11.6 m/yr). Dotted lines depict model predictions for setting rates of 6 and 14 m/yr.

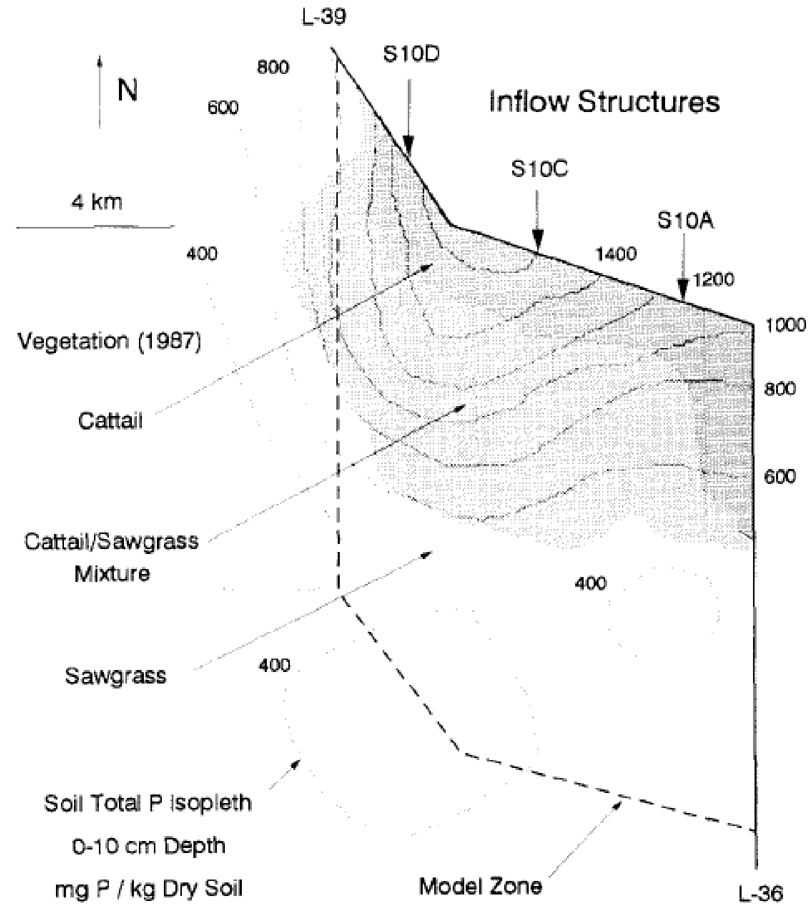
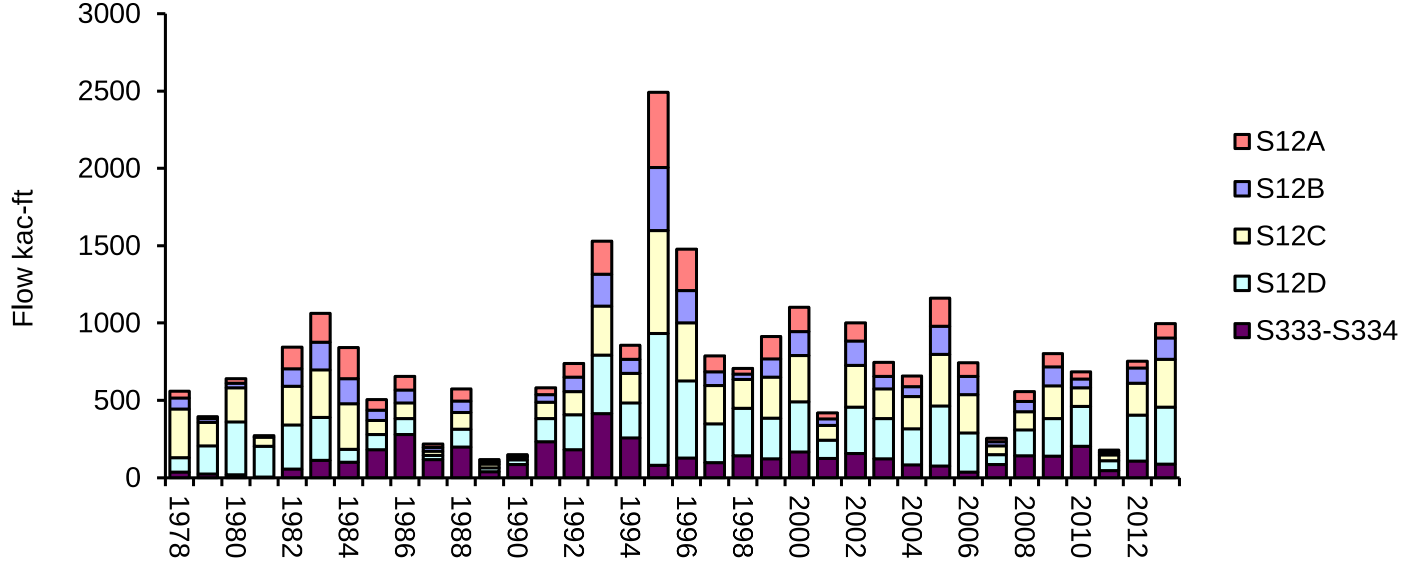


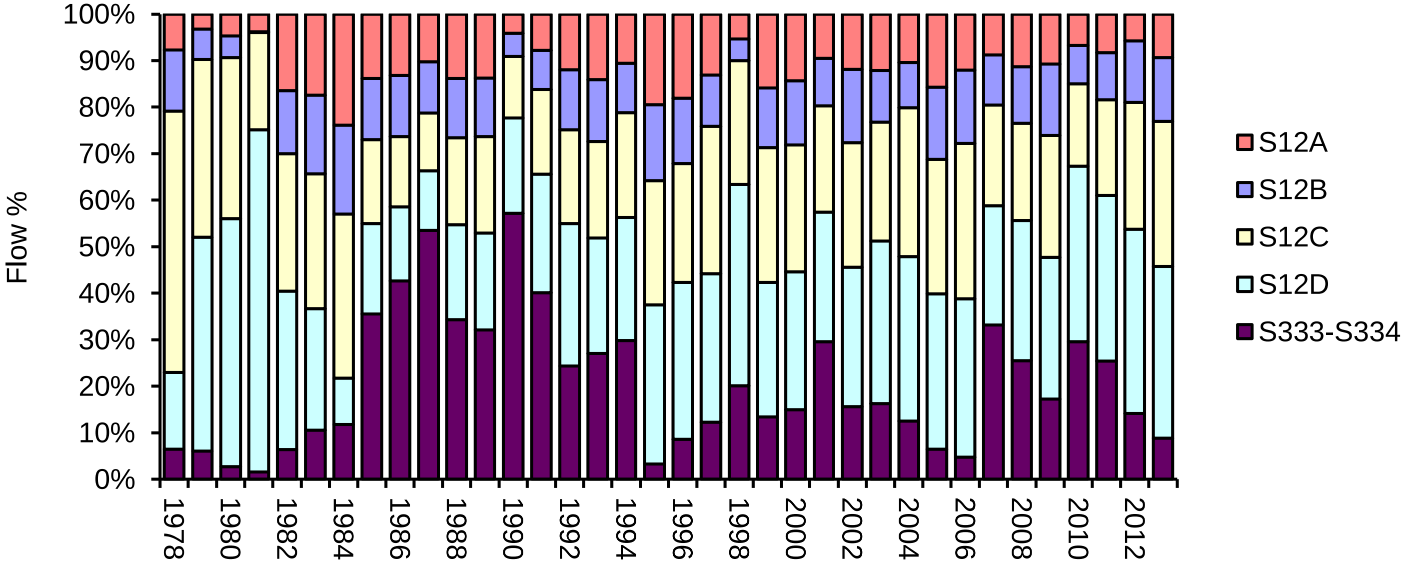
Figure 2. Cattail and Soil Phosphorus Distribution in S-10 Inflow Zone of Water Conservation Area 2A. Figure depicts boundary of model zone, gradients in vegetation (Urban *et al.*, 1993), and gradients in soil phosphorus (Reddy *et al.*, 1993; DeBusk *et al.*, 1994). Regional map is shown in Figure 1.

Cornerstones of ENP Inflow P Limits

- Structure data best available & representative of marsh immediately downstream
- Target (50th percentile ~ 8 ppb) for IL and LTL anchored in 1978-1979 OFW period.
- Water year time step to reduce variability & remove seasonal variations
- Statistical Model with Terms accounting for:
  - Trends in the historical data
  - Hydrologic variations (flow as surrogate)
  - All other factors and variations reflected in the calibration dataset
- Similar model used for Refuge, BMP Rule, and trend analysis literature.
- Longer period (1978-1990) used for calibration to calibrate consider effects of hydrologic and other sources of variation.
  - Interim Limits calibrated to S12+ (S333-S334) data
  - Longterm Limits calibrated to S12 data ~less impacted by canal flows
- Maximum Type I error of 10%; lower value would increase risk of Type II error (false negative, impacts marsh, failure to meet SA objective)



Flow kac-ft
3000
2500
2000
1500
1000
500
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
S12A
S12B
S12C
S12D
S333-S334



Flow %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
S12A
S12B
S12C
S12D
S333-S334

Appendix A Regression Equation

$$Y = Ym + b_1 (T - Tm) + b2 (Q - Qm) + E \qquad (2)$$

where

Y	=	observed annual, flow-weighted-mean concentration (ppb)
T	=	water year (1978-1990)
Q	=	basin total flow (1000 acre-ft/yr)
E	=	random error term
m	=	subscript denoting average value of Y, T, or Q in calibration period

Regional Applications of Conceptual Model

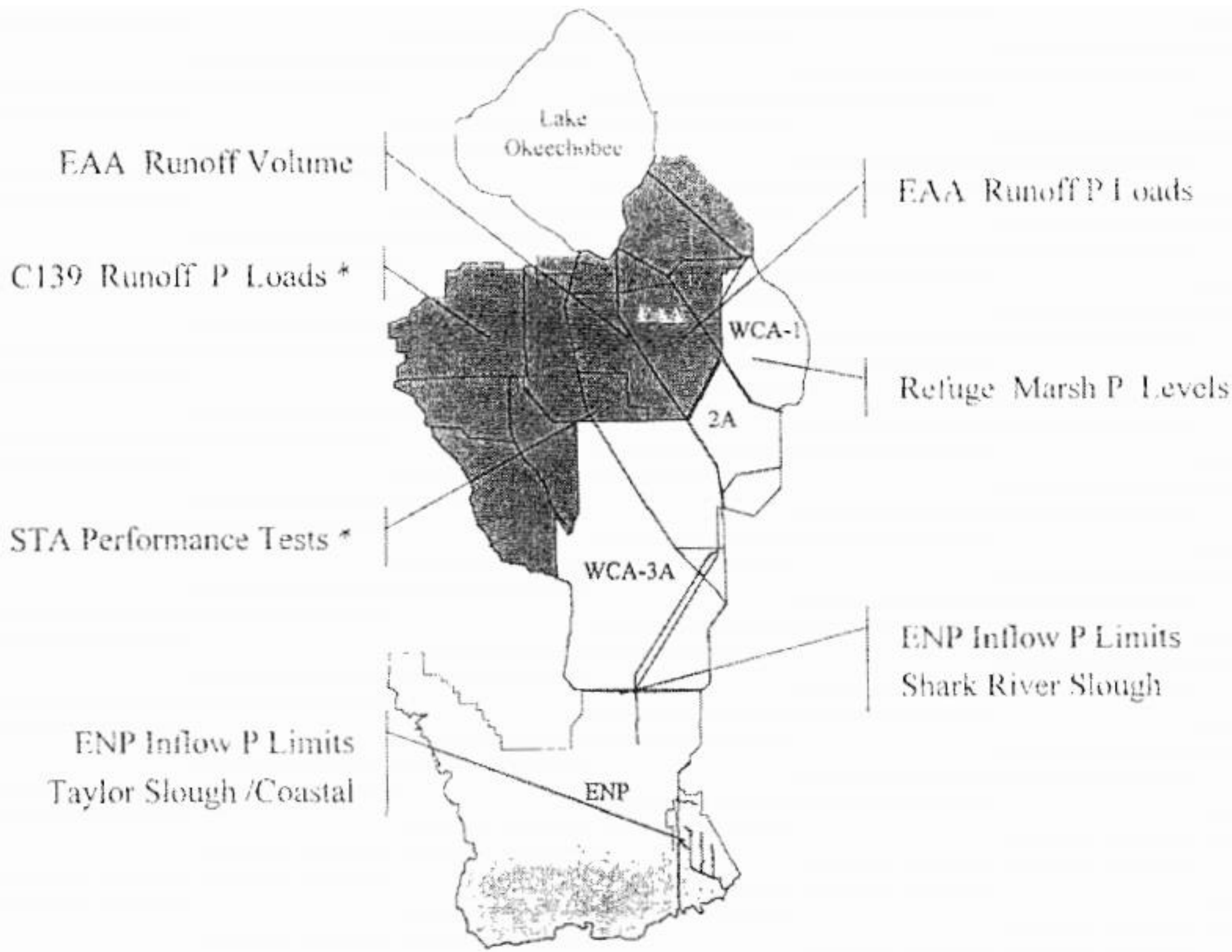


FIGURE 19.1 Regional map.

Introduction

During the designated OFW baseline year (March 1, 1978 - March 1 ,1979), inflows to ENP's Shark River Slough had a flow-weighted-mean phosphorus concentration of 6 ppb. During the first year of monitoring by SFWMD (October 1983-September 1984), inflows to ENP's Taylor Slough and Coastal Basins had a flow-weighted-mean phosphorus concentration of 5.8 ppb. In addition to specifying the baseline period for deriving water quality limits, OFW regulations require that seasonal and other cyclical variations of natural origin be taken into account. Accordingly, ENP inflow limits are derived below considering three sources of variation in the annual flow-weighted-mean concentration:

(1) Hydrologic - correlations with basin total flow, to reflect wet-year vs. dry-year influences on water quality;

(2) Trend - correlations with time, to permit adjustment of the standards to the baseline year; and

(3) Random variations - attributed to sampling variations, analytical variations, and other phenomena.

Consideration of these sources of variation leads to Interim Shark River Slough limits ranging from 9 ppb in wet years to 14 ppb in dry years, considerably above the 6 ppb measured during the OFW baseline year. A similar approach is taken in deriving levels for marsh stations in Loxahatchee National Wildlife Refuge, with the exception that hydrologic variations are represented by correlations with water surface elevation.

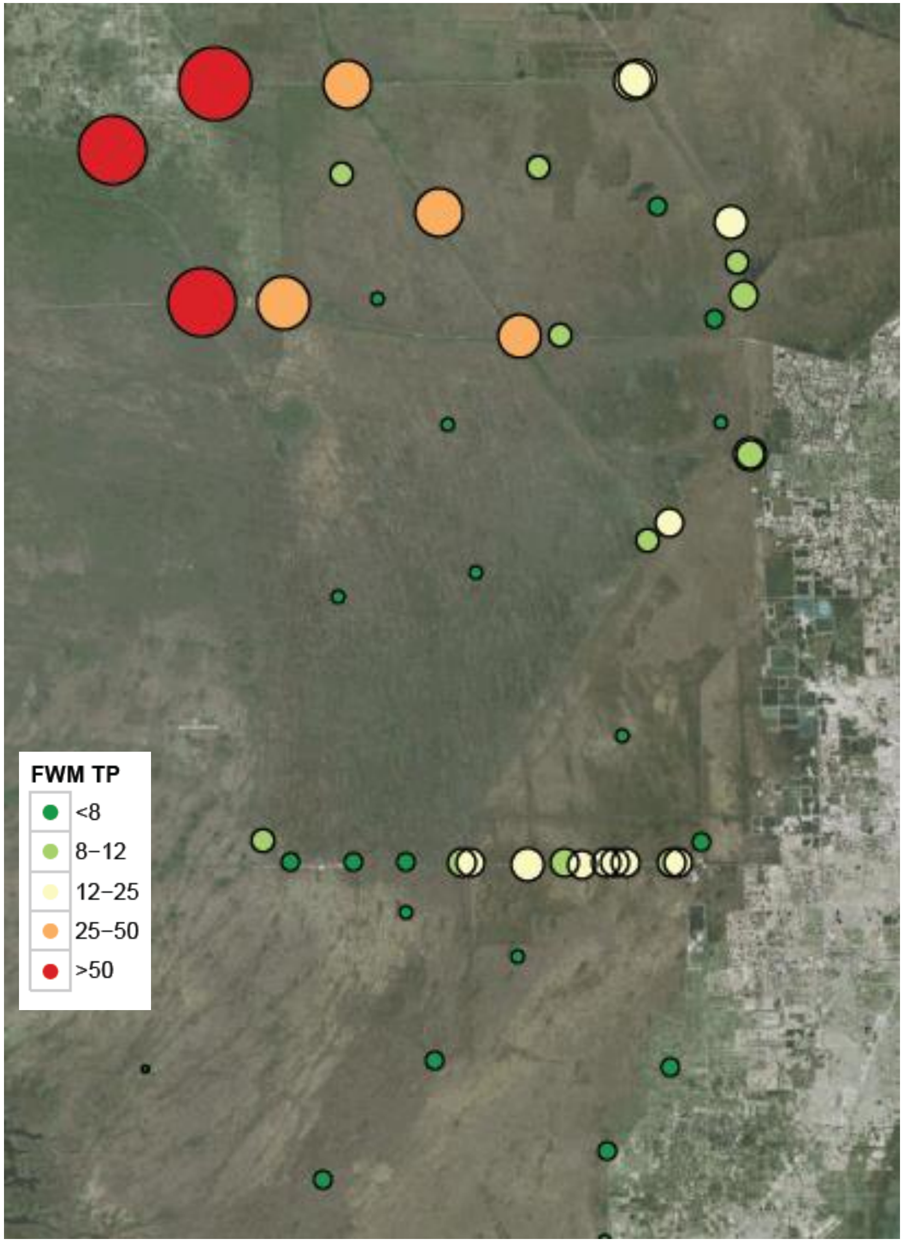
Everglades SWIM Plan - Appendix E

LIMITS FOR THE ESTIMATED ANNUAL FLOW-WEIGHTED AVERAGE CONCENTRATION OF TOTAL PHOSPHORUS IN THE DISCHARGE TO SHARK RIVER SLOUGH

Data exists for inflow to Shark River Slough occurring through the S12 structures during the period of record 12/1/77 - 9/30/90 and through S333 during 10/1/78 - 9/30/90. Interim water quality limits will be derived from composite flow and total phosphorus concentrations of S-333 and the S-12's. In the long term, modifications proposed by the U.S. Army Corps of Modified Water Delivery GDM will significantly reduce but may not eliminate flows through S-333. The proposed modifications will utilize new structures in the L-67A canal to pass water from WCA-3A to 3B and then to Northeast Shark River Slough via structures in the L-29 (S-355). Approximately 45% of the Park water delivery will be made through the S-12's with the remaining 55% directed throu S-355 into Northeast Shark River Slough. If downstream conditions prevent meeting the targeted 55% delivery through S-355, S333 would be opened to make up the difference in the actual and targeted amounts delivered to Northeast Shark River Slough. Since the long term flows through S-333 will be minimal, these limits will be based on S-12 concentrations. In either case the limits are set by utilizing data from this period of record to statistically project back to the 1978-79 baseline period of 2 water years to obtain a benchmark. The 2 year baseline

WRONG!

Potential future operations did not influence derivation of the ENP inflow P target, interim limit, or long-term limit. Flows & phosphorus loads from S-333 were excluded in deriving the long-term limit to better represent less-impacted marsh inflows and minimize the influence of anthropogenic, canal sources on the mean and variability of the ENP inflow TP concentrations occurring after the 1978-1979 base period. It was assumed that elevated TP concentrations associated with canal flows would be reduced with implementation of upstream source controls (BMPs and enhanced STAs), as has been observed. With sufficient reductions in canal concentrations, compliance would be insensitive to future changes in facilities or operation to provide hydrologic restoration.



Flow-Weighted Means
2002-2013
Wet Season

Elevated TP at S333 and eastern L29 traced to upstream canal sources

Details: http://www.wwwalker.net/ever_toc

TABLE 2. CALCULATION OF LONG TERM LIMITS FOR SHARK RIVER SLOUGH

10% REJECTION LIMIT ON ANNUAL MEAN TOTAL PHOSPHORUS ([tp] ppb)
DETRENDED AND ADJUSTED FOR ANNUAL TOTAL FLOW TO ENP
S12 flow weighted mean [tp] vs S12+S333 composite annual Q
1 1980 OUTLIER DELETED

1Oct-30Sep year	[tp] ppb	Q 1000 acre feet	Fitted ppb	Detrended ppb	10% Rejection Limit ppb
78	6.72	522.803	8.3	8.6	10.4
79	8.76	407.050	9.4	9.2	11.1
80	10.47	649.164	8.6	7.9	9.7
81	12.22	291.687	10.9	9.8	11.8
82	7.92	861.328	8.3	6.8	8.6
83	6.89	1061.258	7.7	5.7	7.6
84	9.83	842.779	9.3	6.9	8.7
87	14.25	276.623	13.7	9.9	11.9
88	12.82	585.451	12.5	8.2	10.1
89	14.42	116.860	15.4	10.8	12.8
90	15.50	148.219	15.7	10.6	12.7

Average = 8.6

$R^2 = .88865$

Standard error of estimate: $s = 1.17116$

Fitted [tp] $= 10.8909 + .4449(\text{year} - 83.727) - .00538(Q - 523.929)$

$= a + b \cdot \text{year} + c \cdot Q$

$= -23.5419 + .4449 \cdot \text{year} - .00538 \cdot Q$

Standard errors: ± 8.3687 $\pm .0963$ $\pm .00131$

Detrended [tp] $= (a + b \cdot 78.5) + c \cdot Q$

$= 11.38 - .00538 \cdot Q$

Standard errors: ± 1.06 $\pm .00131$

$$\text{Upper Limit} = \text{Detrended[tp]} + t\sqrt{[s^2 + s^2/n + \text{var}(b) \cdot (78.5 - 83.727)^2 + \text{var}(c) \cdot (Q - 523.929)^2 + 2 \cdot \text{cov}(b,c) \cdot (78.5 - 83.727) \cdot (Q - 523.929)]}$$

$$\text{Upper Limit} = 11.38 - .00538 \cdot Q + 1.397 \cdot \sqrt{[2.493 - .00231 \cdot Q + .00000170 \cdot Q^2]}$$

Trend Term in Limit Equation

- Account for Increasing Trends in P Concentration
- Adjust calibration data set (1978-1990) to target period (1978-1979)
- Trends confirmed using various statistical methods
  - Seasonal Kendall Tests, Walker (1991)
  - Other exploratory analyses & statistical models
  - Appendix A regression equations
- De-trending the mean does not adjust for increased variations induced by S333 operations after the 1978-1979 base period. Those variations accounted for the higher interim vs. long-term limits.

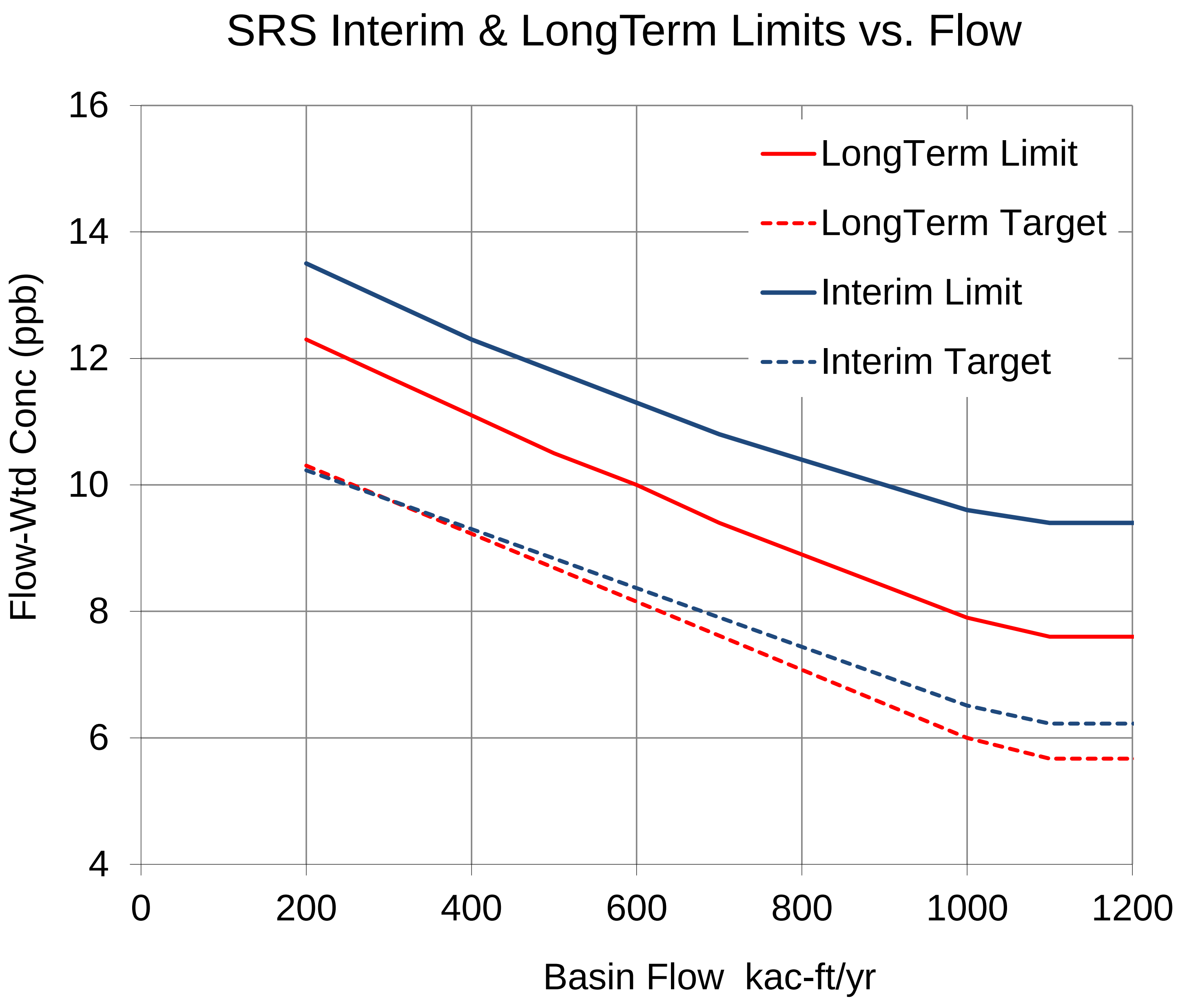
Flow Term in Limit Equation

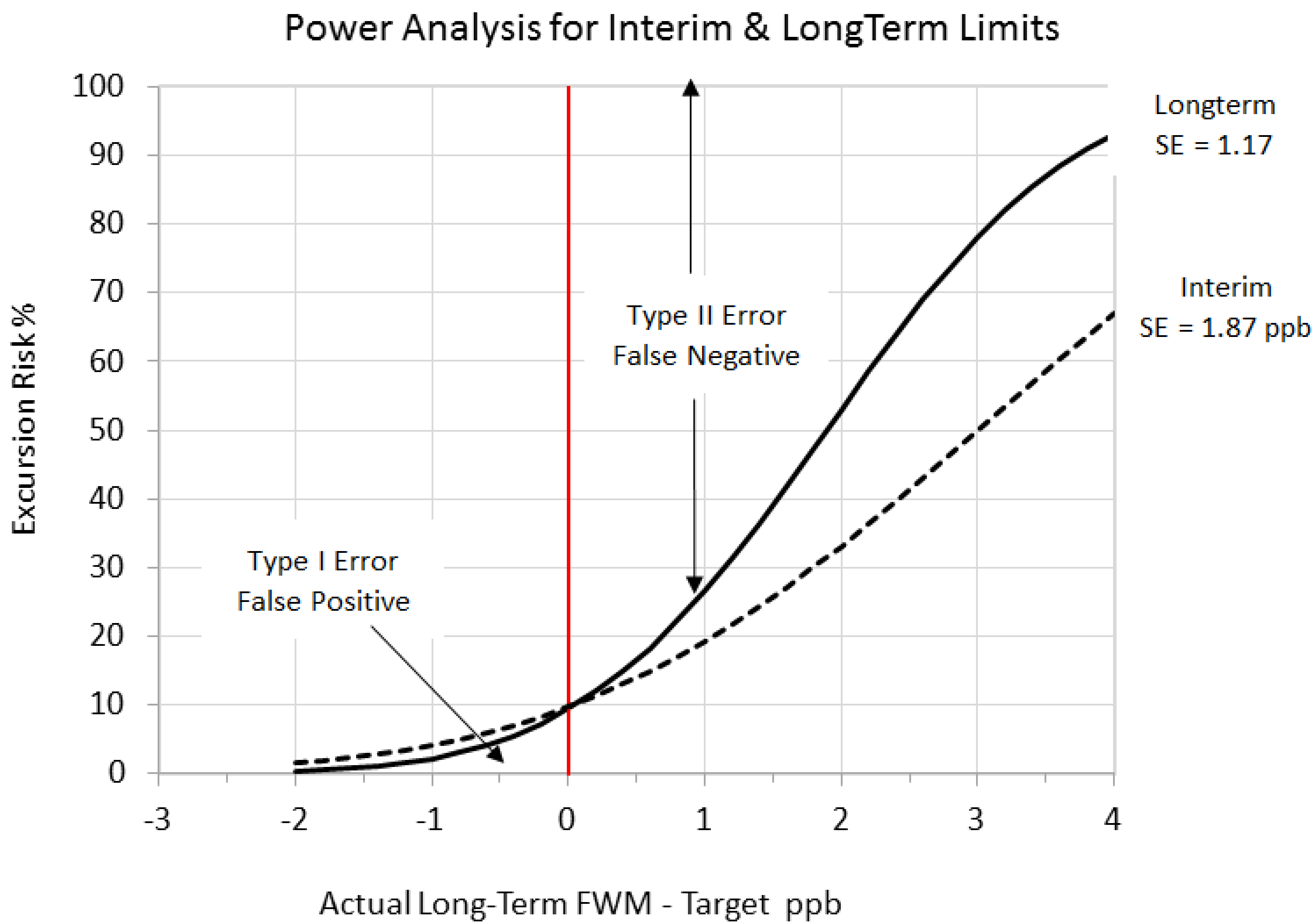
- Flow used as surrogate for effect of hydrologic variations on P transport to Park
- Mechanisms potentially responsible for decreasing P with increasing flow
  - Higher stages in WCA-3A
  - Marsh P decreases with increasing depth
  - Longer hydroperiod allowing for greater P uptake in WCA-3A marsh
  - Larger marsh area due to WCA-3A topographic variations
  - Less short-circuiting of flows & P loads down Miami canal to L67 & S333
  - Greater dilution by rainfall evenly distributed over marsh with low TP < 5 ppb.
  - Lower fraction of flow thru S333 vs. S12X.
- Explaining variations related to flow
  - reduces variability & improves accuracy of test (less Type I & Type II error).
  - Eliminates bias in wet vs. dry years; without flow term Type I error would be >>10% in dry years and <<10% in wet years. Excursions would be difficult to interpret.
  - Increases power for detecting trends in compliance metric.
- Concept of adjusting time series for hydrologic variations to increase power for trend detection developed by USGS (Hirsch, Helsel, et al.... 1982-1984)
- Flow/concentration correlation in ENP inflows initially identified by SFWMD

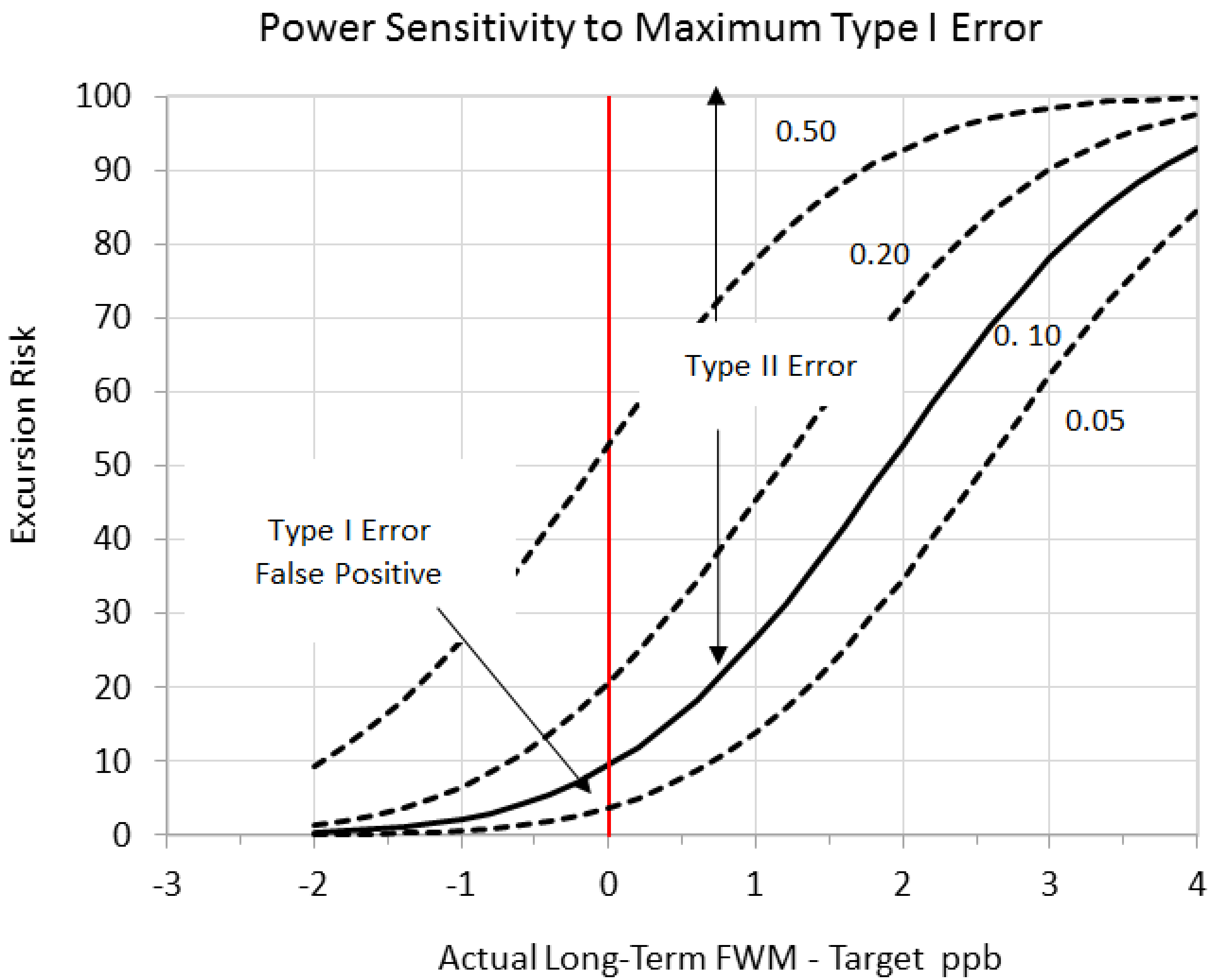
Random Variation Term in Limit Equation

- Factors Embedded in the Random Variability Term / Kitchen Sink
  - Sampling & Analytical Measurement Error in the Calibration Dataset
  - Natural Variations
  - Operational Variations
  - All other factors in the calibration dataset not explicitly considered in the equation (long-term trend, flow correlation)

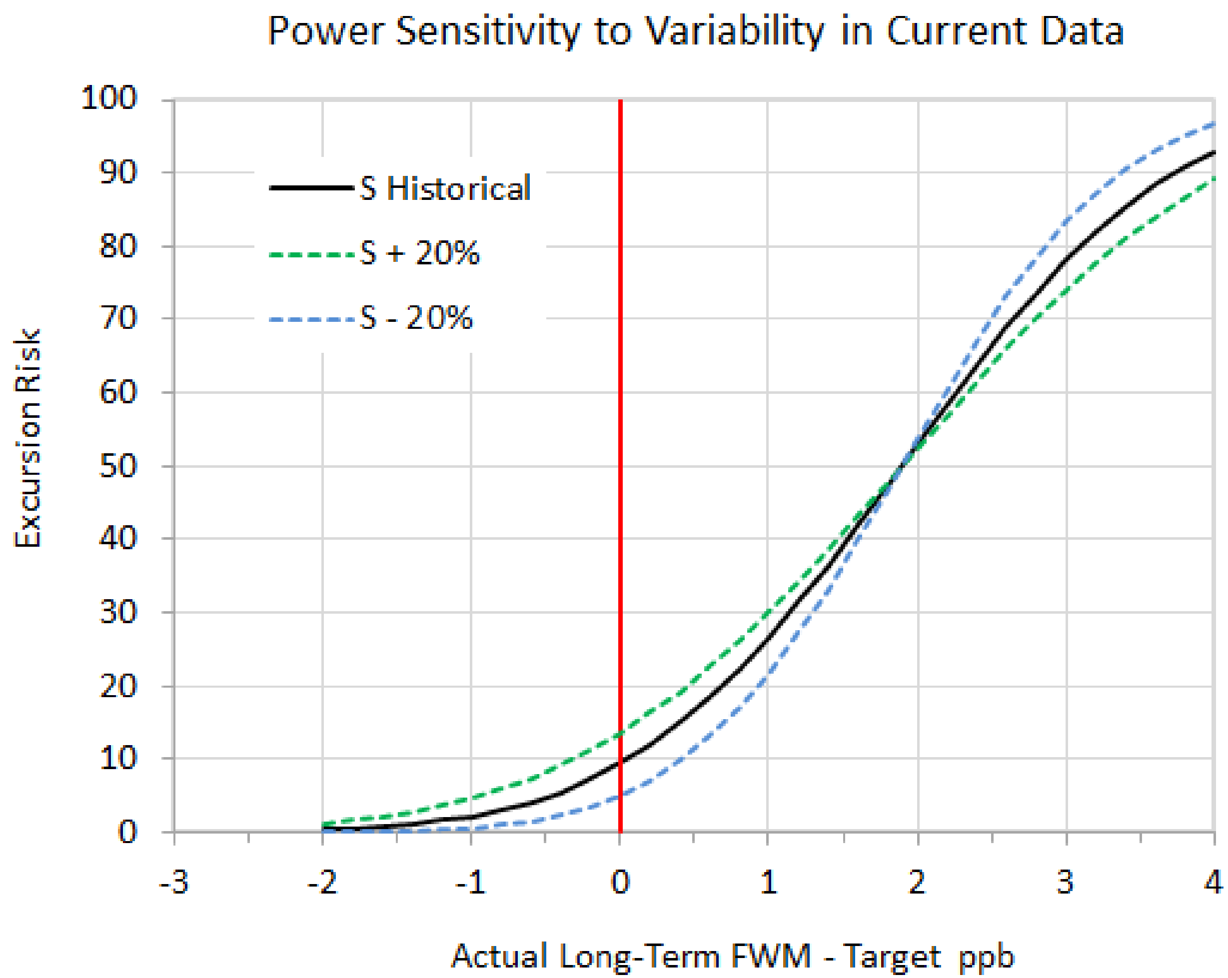
- Factors Determining Difference between Target (50^{th} %) and Limit (90^{th} %)
  - Standard Deviation of Random Variation Term
  - Including source with highest concentration (S333) substantially increased the random variation term. Standard deviation ~1.9 ppb for Interim vs. ~1.2 ppb for Longterm Limits. The increased variations likely reflected increased magnitudes and variations in S333 flows occurring after the OFW base period and could not be factored into Long-term Limits.
  - Number of Years in calibration dataset (t statistic)
  - Assumed Maximum Type I error (10%);
  - Actual Type I error likely to be lower now because of QA/QC improvements.


SRS Interim & LongTerm Limits vs. Flow
Flow-Wtd Conc (ppb)
16
14
12
10
8
6
4
0
200
400
600
800
1000
1200
Basin Flow kac-ft/yr
LongTerm Limit
LongTerm Target
Interim Limit
Interim Target


Power Analysis for Interim & LongTerm Limits
Excursion Risk %
Actual Long-Term FWM - Target ppb
100
90
80
70
60
50
40
30
20
10
0
-3
-2
-1
0
1
2
3
4
Longterm
SE = 1.17
Interim
SE = 1.87 ppb
Type II Error
False Negative
Type I Error
False Positive



Power Sensitivity to Maximum Type I Error
Excursion Risk
100
90
80
70
60
50
40
30
20
10
0
-3
-2
-1
0
1
2
3
4
Actual Long-Term FWM - Target ppb
0.50
0.20
0. 10
0.05
Type II Error
Type I Error
False Positive

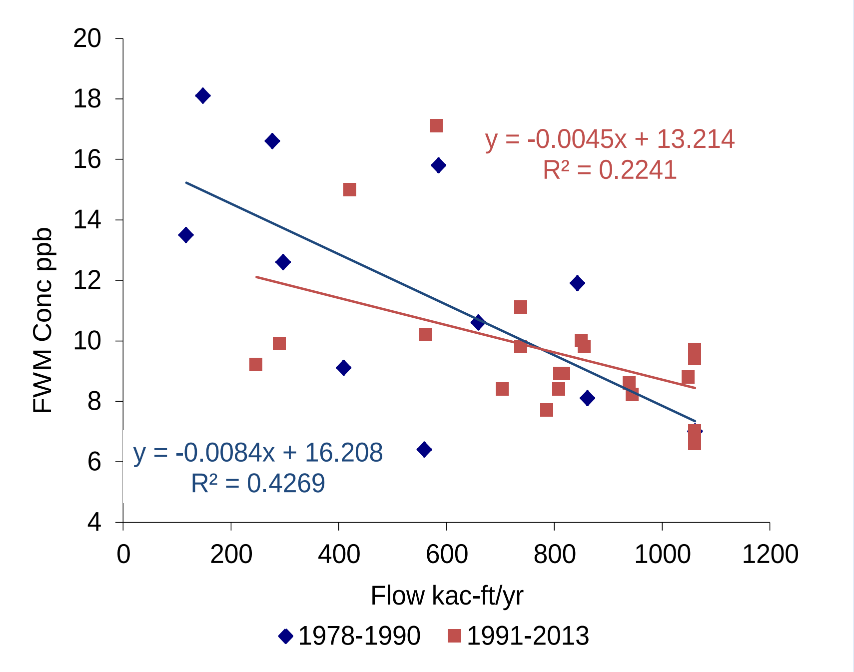


Power Sensitivity to Variability in Current Data
S Historical
S + 20%
S - 20%
Excursion Risk
Actual Long-Term FWM - Target ppb

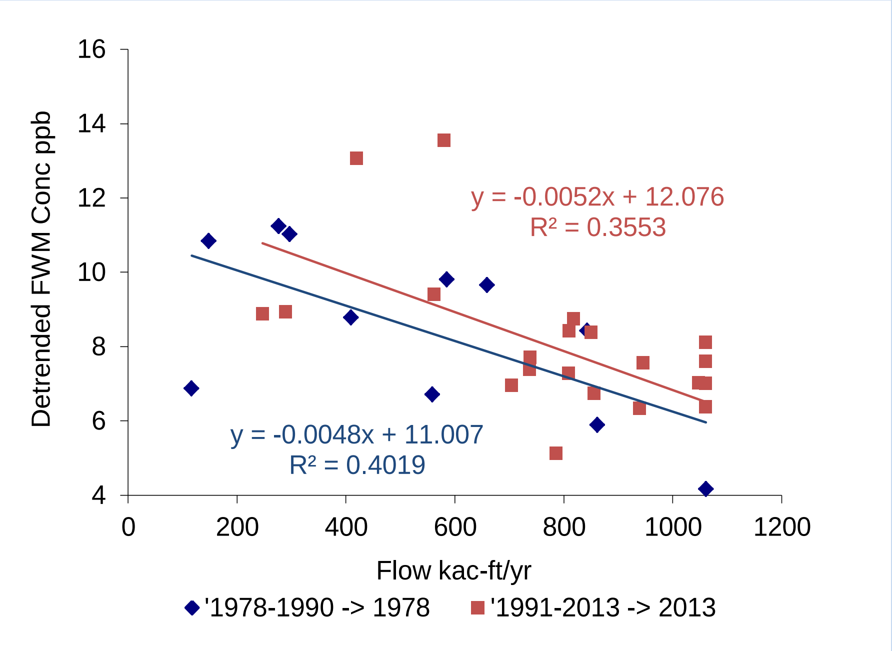
Recent Data

The Flow/Conc. Relationship Has Not Changed
FWM Conc. vs. Basin Flow, 1978-1990 vs. 1991-2013

Raw Data

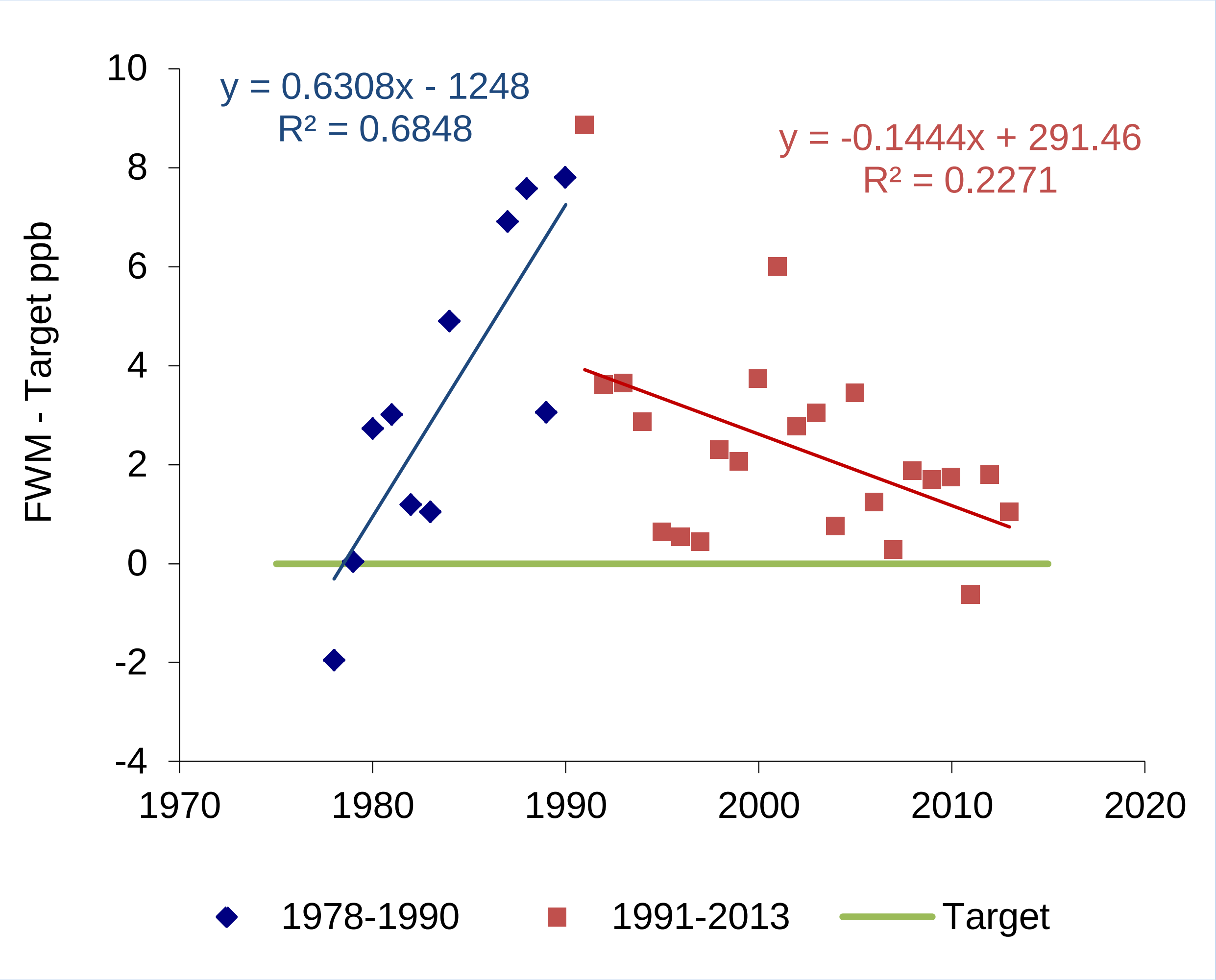


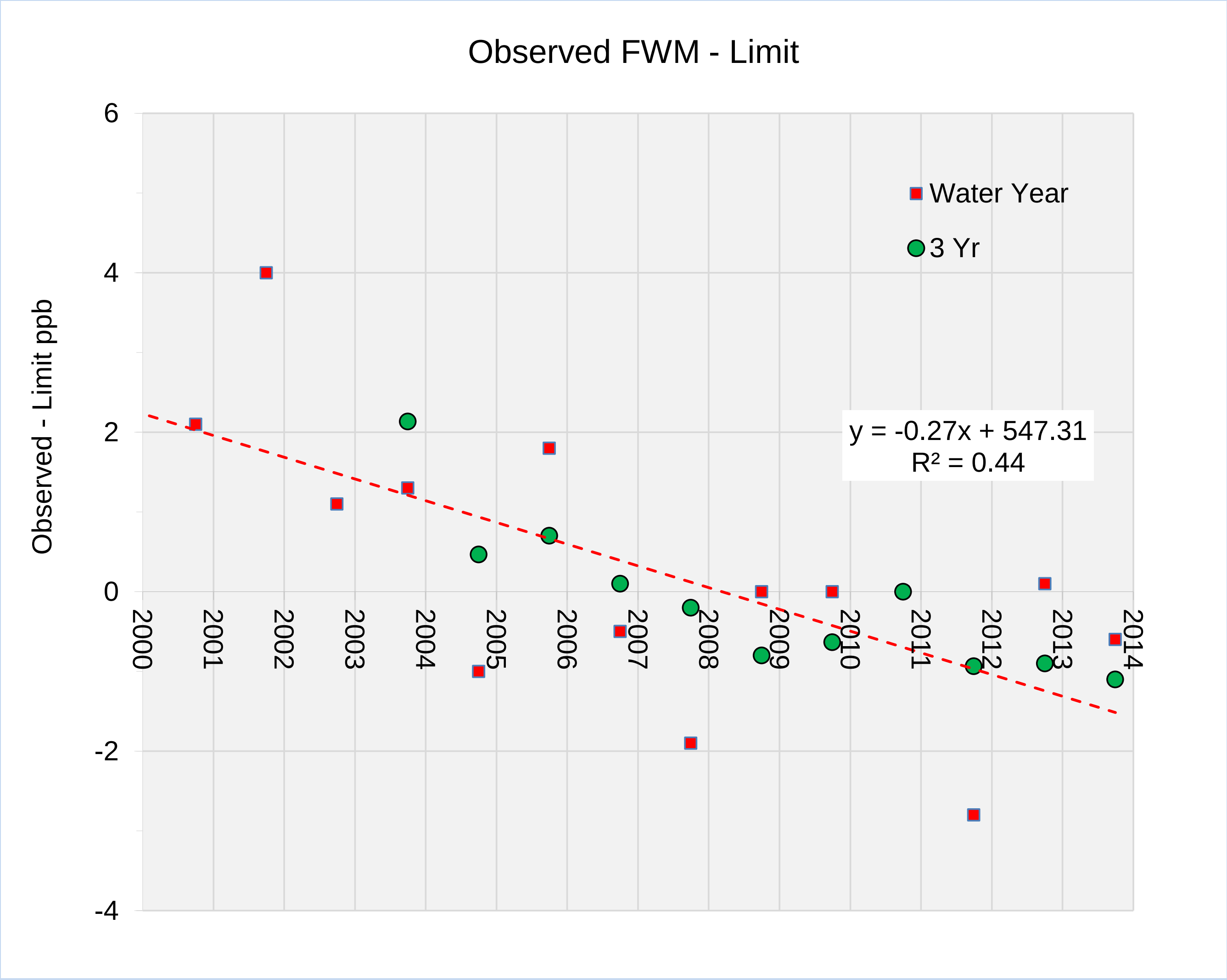
Detrended to 1978 & 2013



Flow constrained to calibration range, X Axis = Min (Water Year Flow, 1061) kac-ft/yr
Separate regressions performed for each period.

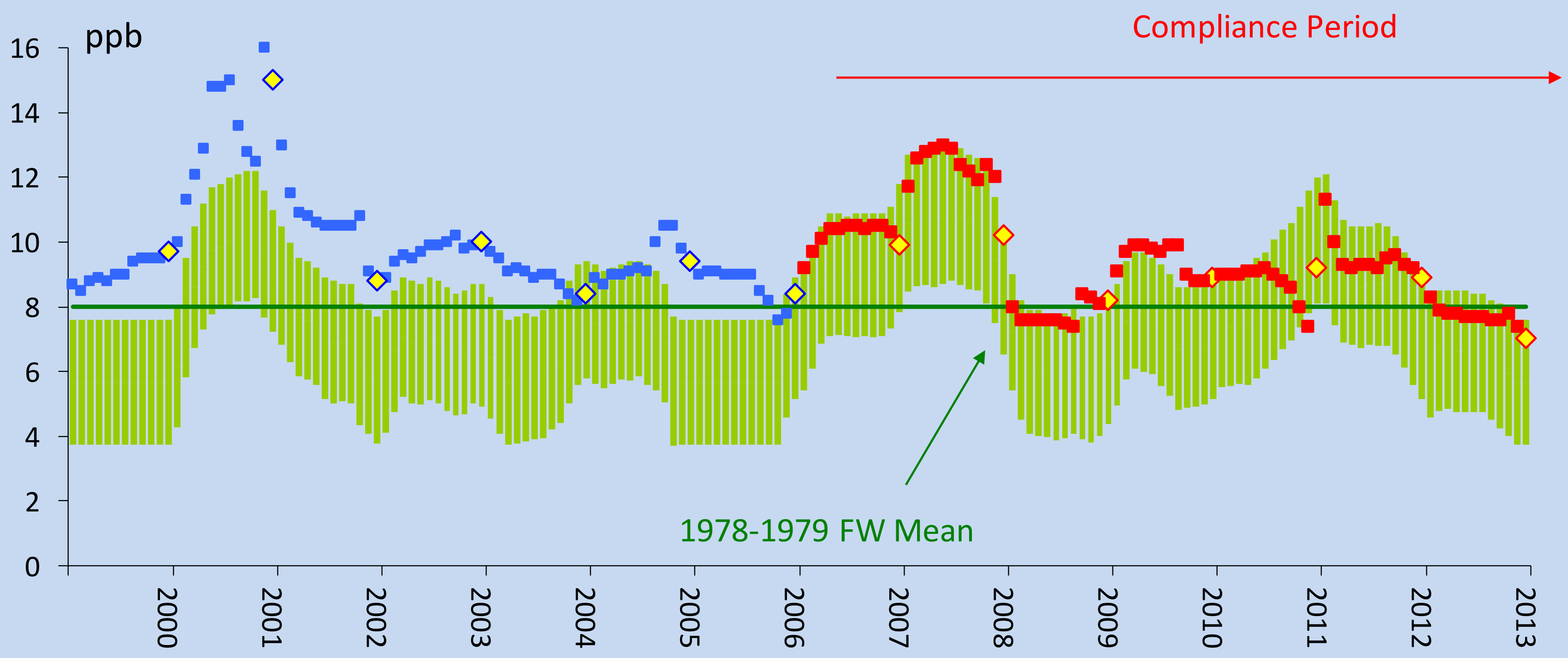
Trends in FWM – Target, 1978-1990 vs. 1991-2013



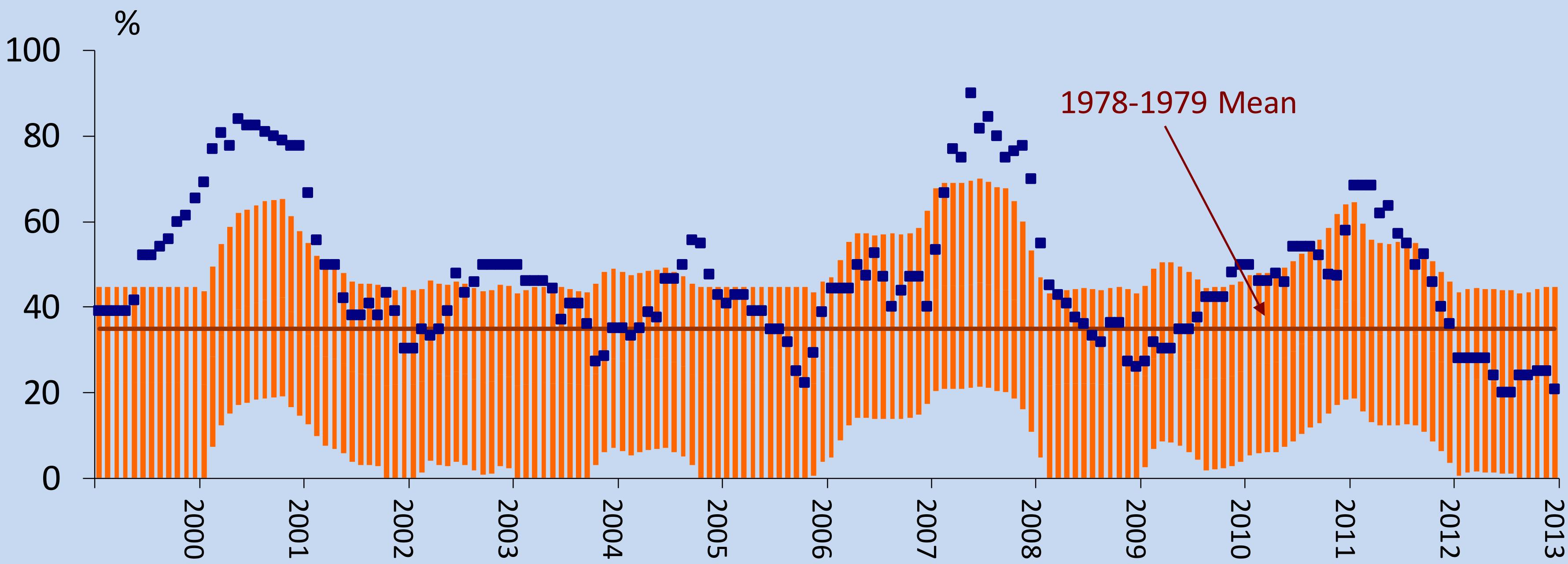


Observed FWM - Limit
Observed - Limit ppb
6
4
2
0
-2
-4
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Water Year
3 Yr
y = -0.27x + 547.31
R² = 0.44

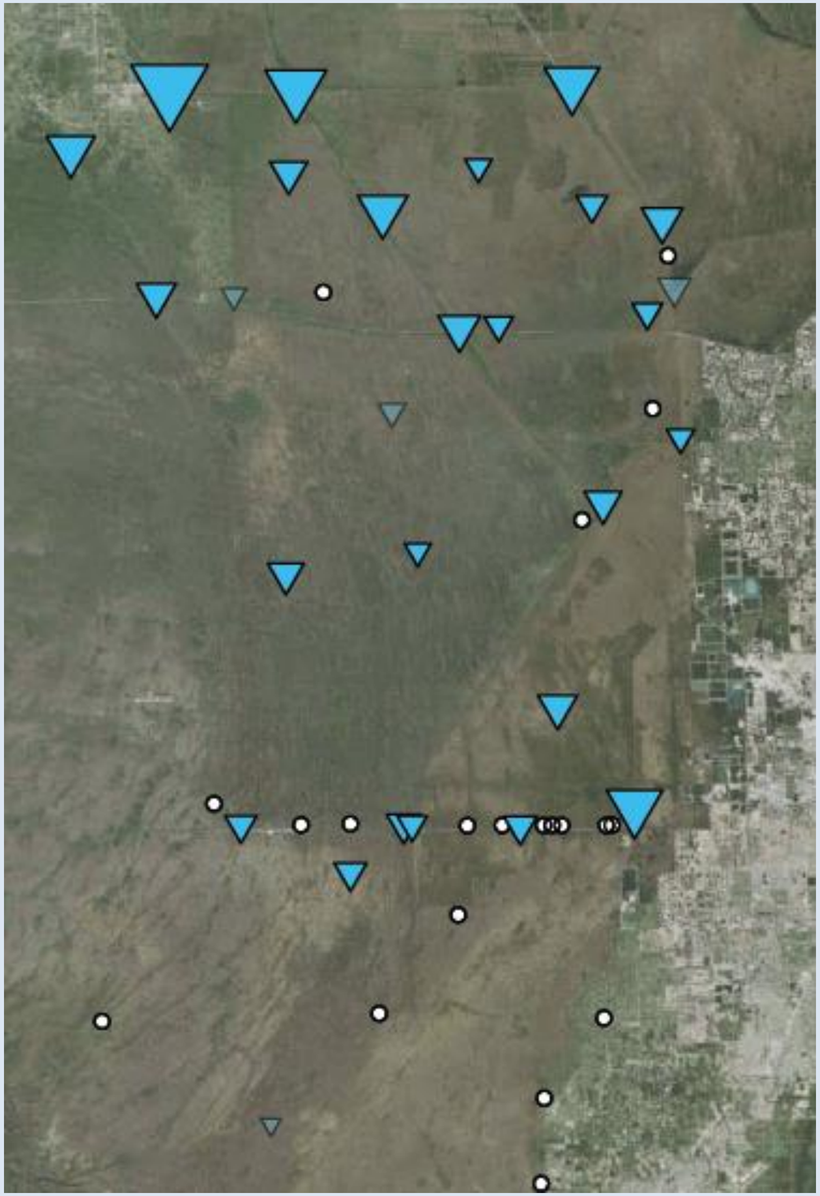
12-Month FWM TP Conc. vs. Target Zone for Long-Term Limits (10th-90th Percentiles), effective Oct 2006.

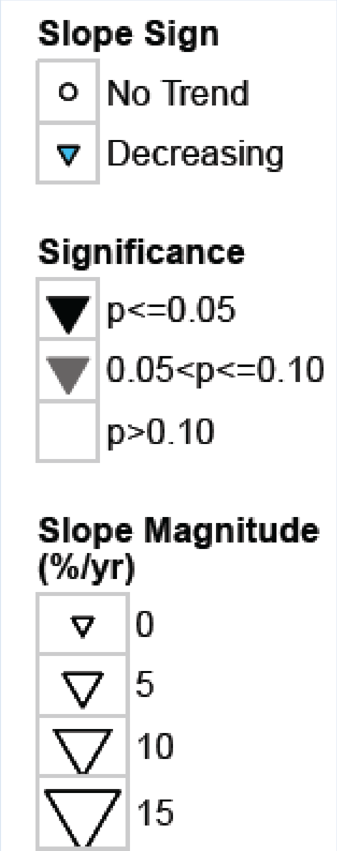


12-Month-Rolling Frequency > 10 ppb vs. Target Zone for Frequency Guideline, (10th-90th Percentiles)



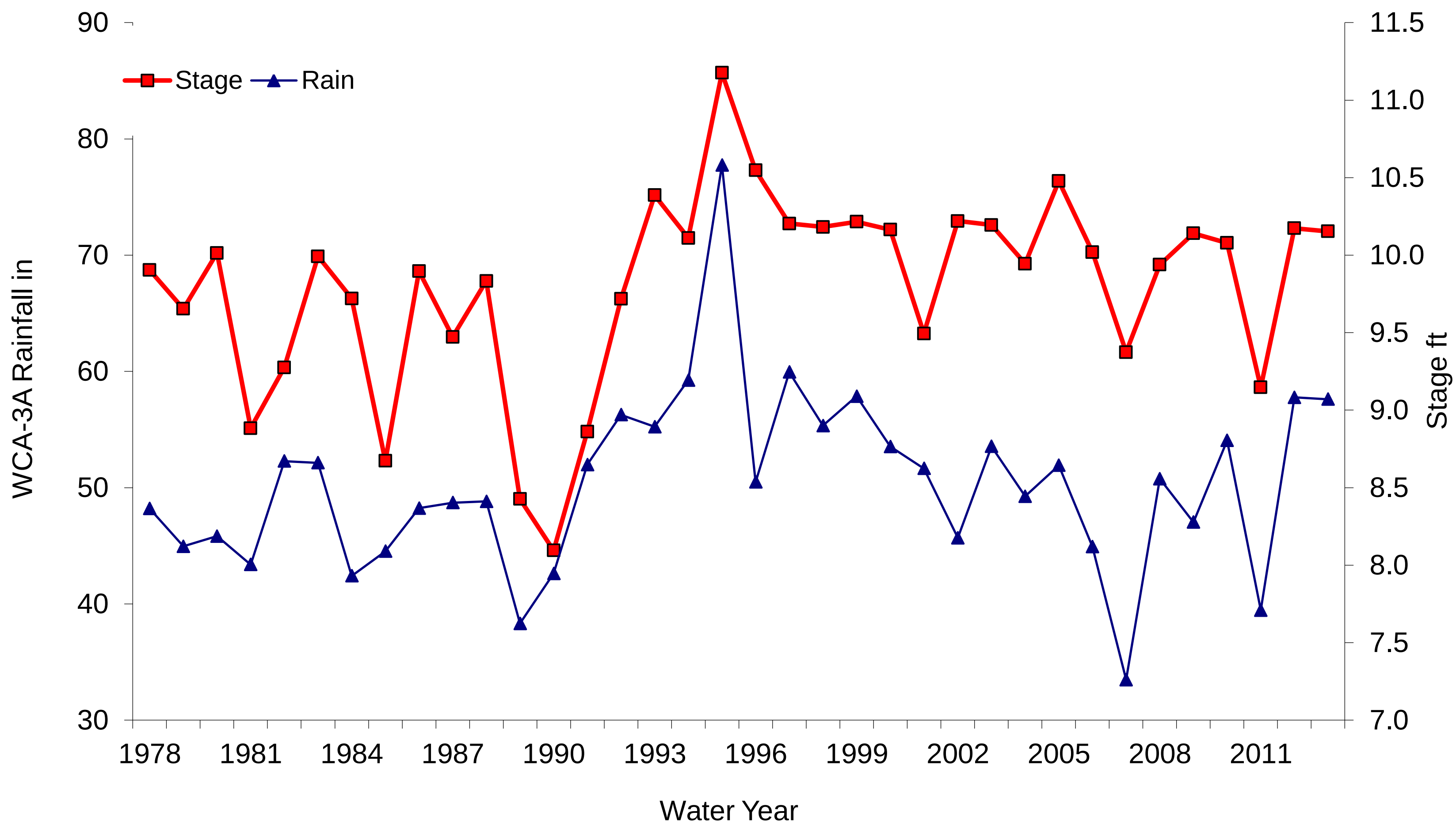
Trends in
Flow-Weighted Means
2002-2013
Wet Season



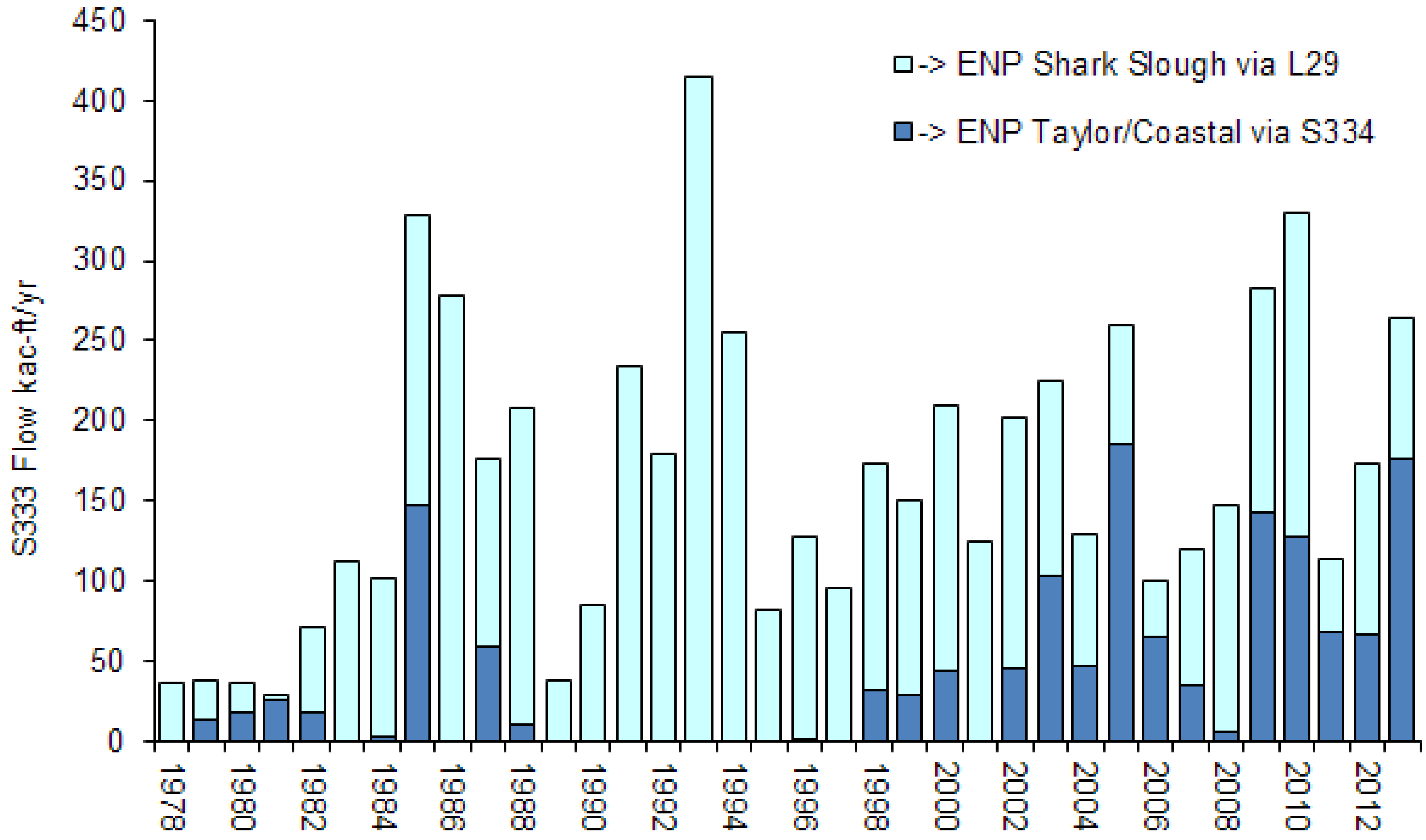


Details: http://www.wwwalker.net/ever_toc

WCA-3A Stage & Rainfall, 1978-2013



Magnitude & Fate of S333 Flow



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VOL. 27, NO. 1 AMERICAN WATER RESOURCES ASSOCIATION FEBRUARY 1991

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William W. Walker[2]

http://wwwalker.net/pdf/wqtrends91.pdf

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Office of Science and Technology
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Nutrient Criteria Technical Guidance Manual

Lakes and Reservoirs

First Edition

11. Interim Phosphorus Standards for the Everglades

by William W. Walker, Jr.

http://wwwalker.net/pdf/pcriteria_everglades_epa2000.pdf

Phosphorus Biogeochemistry *in* SUBTROPICAL ECOSYSTEMS

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19 Long-Term Water Quality Trends in the Everglades

William W. Walker, Jr.

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19.1 ABSTRACT

Long-term water quality and hydrologic monitoring data have provided important bases for defining the Everglades nutrient-enrichment problem, developing interim water quality standards and regulations, designing control measures, and evaluating the effectiveness of control measures. Specific monitoring and data-reduction procedures for determining compliance with interim and long-term objectives are built into the Settlement Agreement (USA et al., 1991), EAA Regulatory Rule (SFWMD, 1992b), and Everglades Forever Act (State of Florida, 1994). These procedures provide measures of performance for the phosphorus control program that are important from ecological, management, and legal perspectives.

Interpretation of monitoring data with respect to long-term or anthropogenic impacts is facilitated by application of a model, which attempts to differentiate long-term, hydrologic, and random variance components. The model has been used to develop tracking procedures for several Everglades locations.

Variations in flow, phosphorus concentration, and phosphorus loads at major structures in the EAA and WCAs over the 1978 to 1996 period are summarized. The structure, calibration, and application of a model for tracking ENP Shark River Slough inflow P concentrations are described. Interpretations and limitations of tracking results are described.

http://wwwalker.net/doi/ever_trends_1999.pdf

The End