Evaluating Nutrient Enrichment Problems in Lake Okeechobee & the Everglades 1989 – 2009

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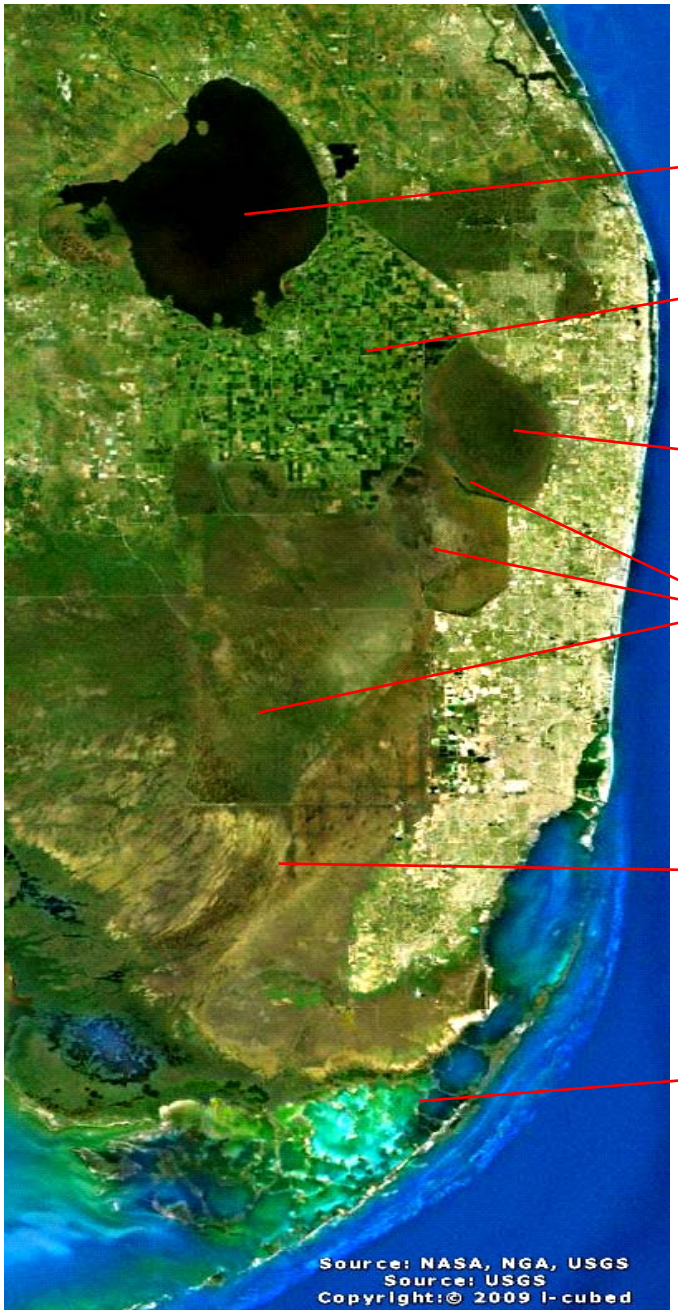
Evaluating Nutrient Enrichment Problems in Lake Okeechobee & the Everglades

- Problem Definition
- Design and Implementation of Remedies
- Statistical Models for Tracking Progress
- Simulation Models for Design

Nutrient Enrichment Problem



Lake Okeechobee

Everglades Agricultural Area

Loxahatchee National Wildlife Refuge

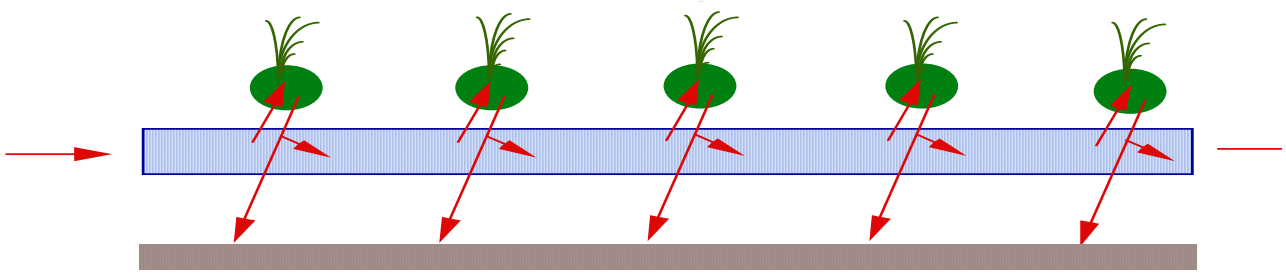
Everglades Water Conservation Areas

Everglades National Park

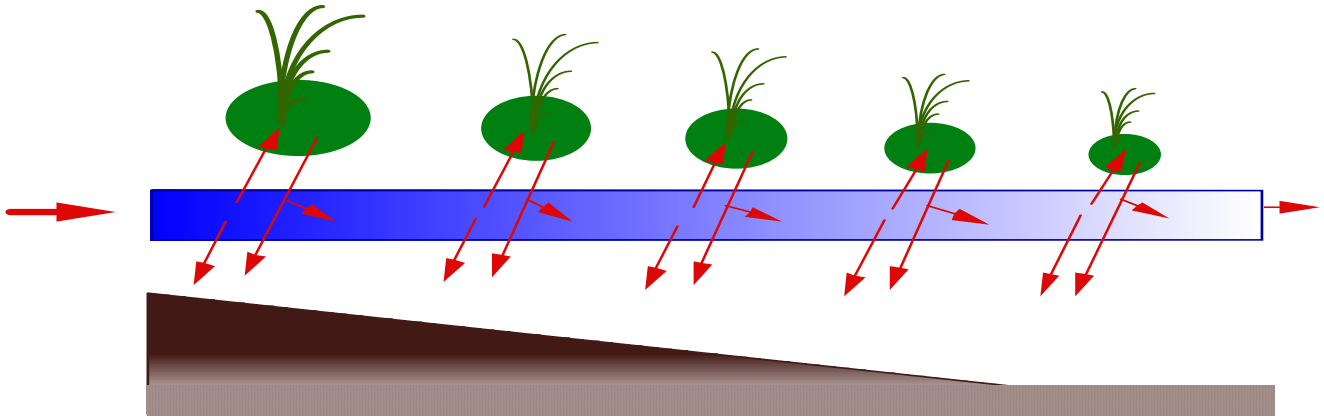
Florida Bay

Phosphorus Gradients in Marsh Vegetation, Water, & Soils Under Baseline & Impacted Conditions

Baseline Conditions: Low Inflow P, No Gradients, Good Habitat for Native Flora & Fauna



Impacted Conditions: High Inflow P, Steep Gradients, Poor Habitat for Native Flora & Fauna



Vegetation Along Phosphorus Gradient in WCA-2A

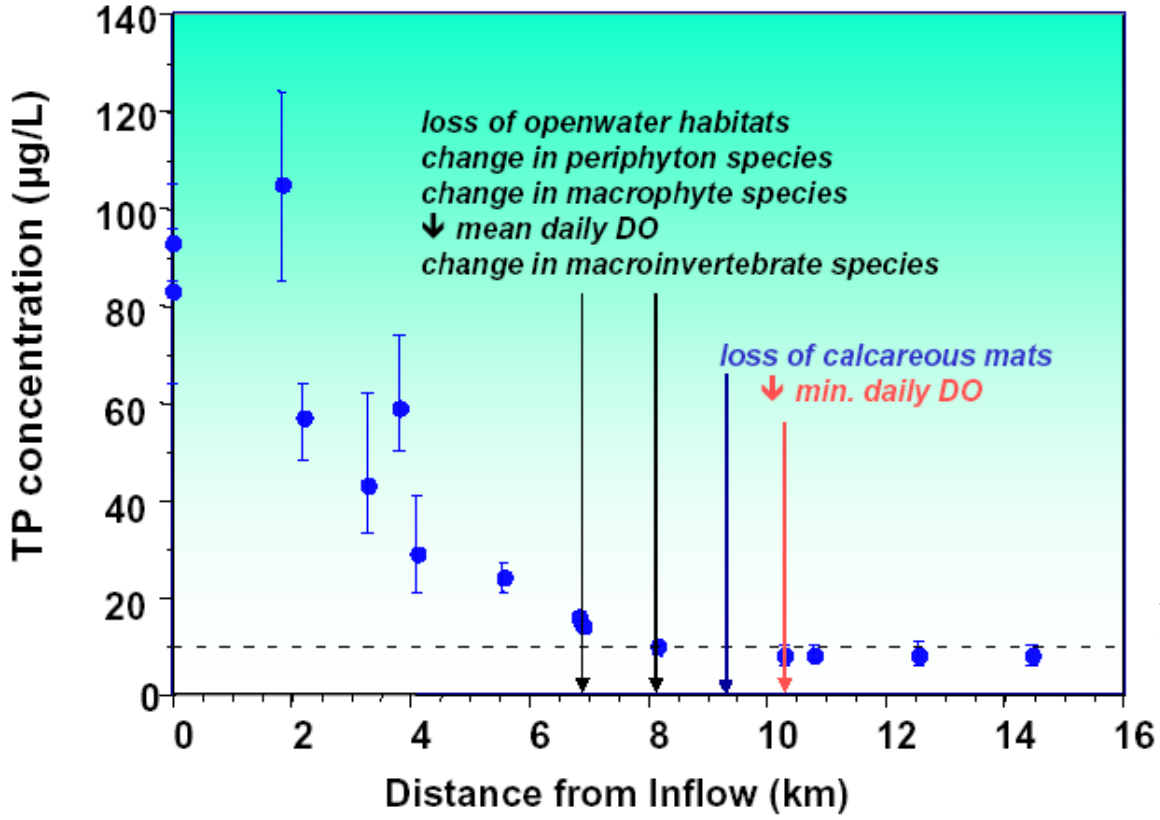
Runoff Pump Station

Cattail

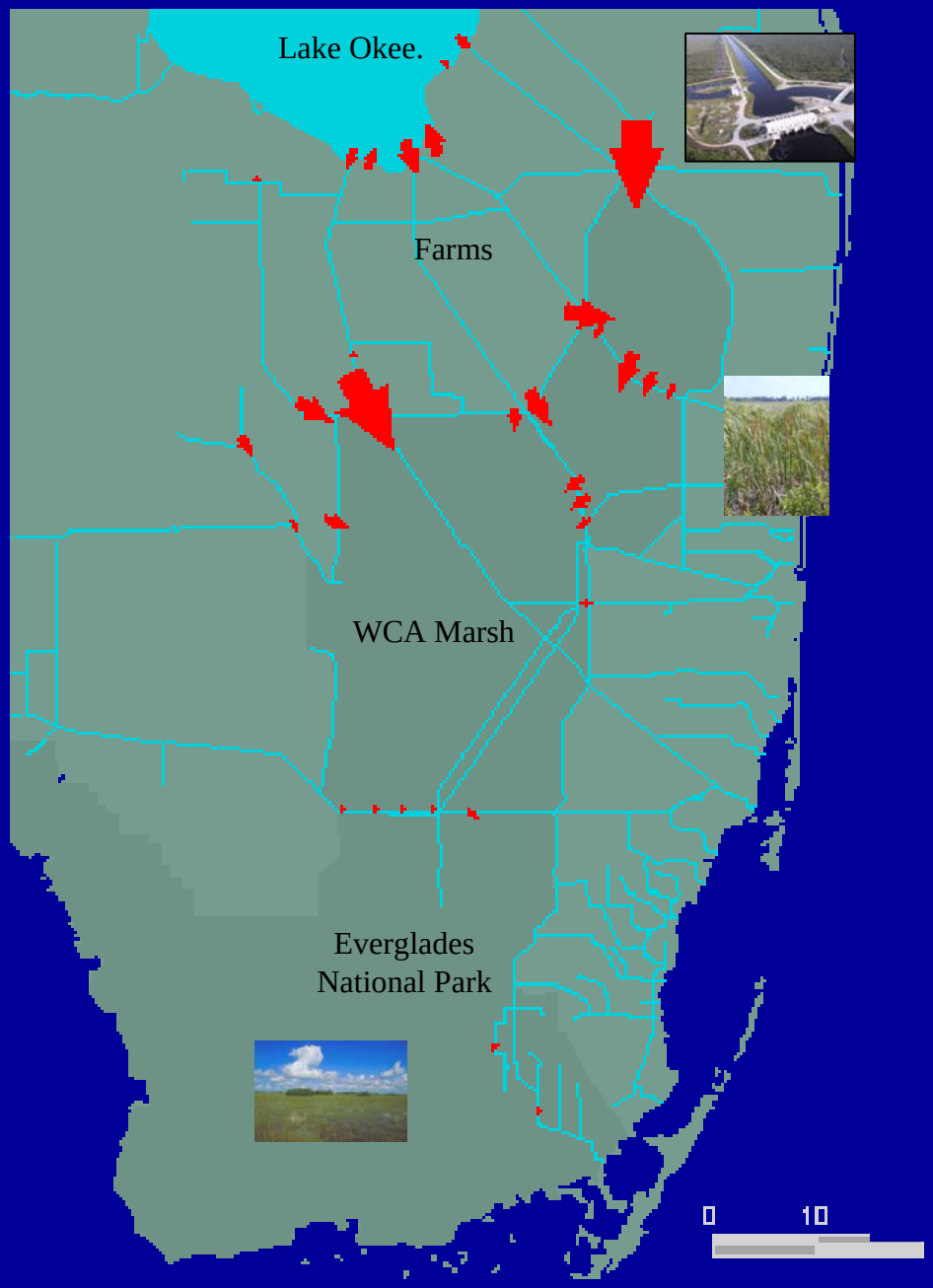
Transition

Sawgrass

Ecological Changes along the WCA-2A Gradient

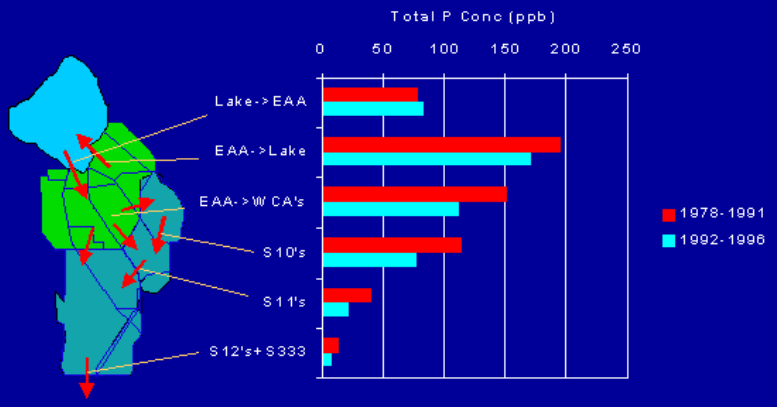


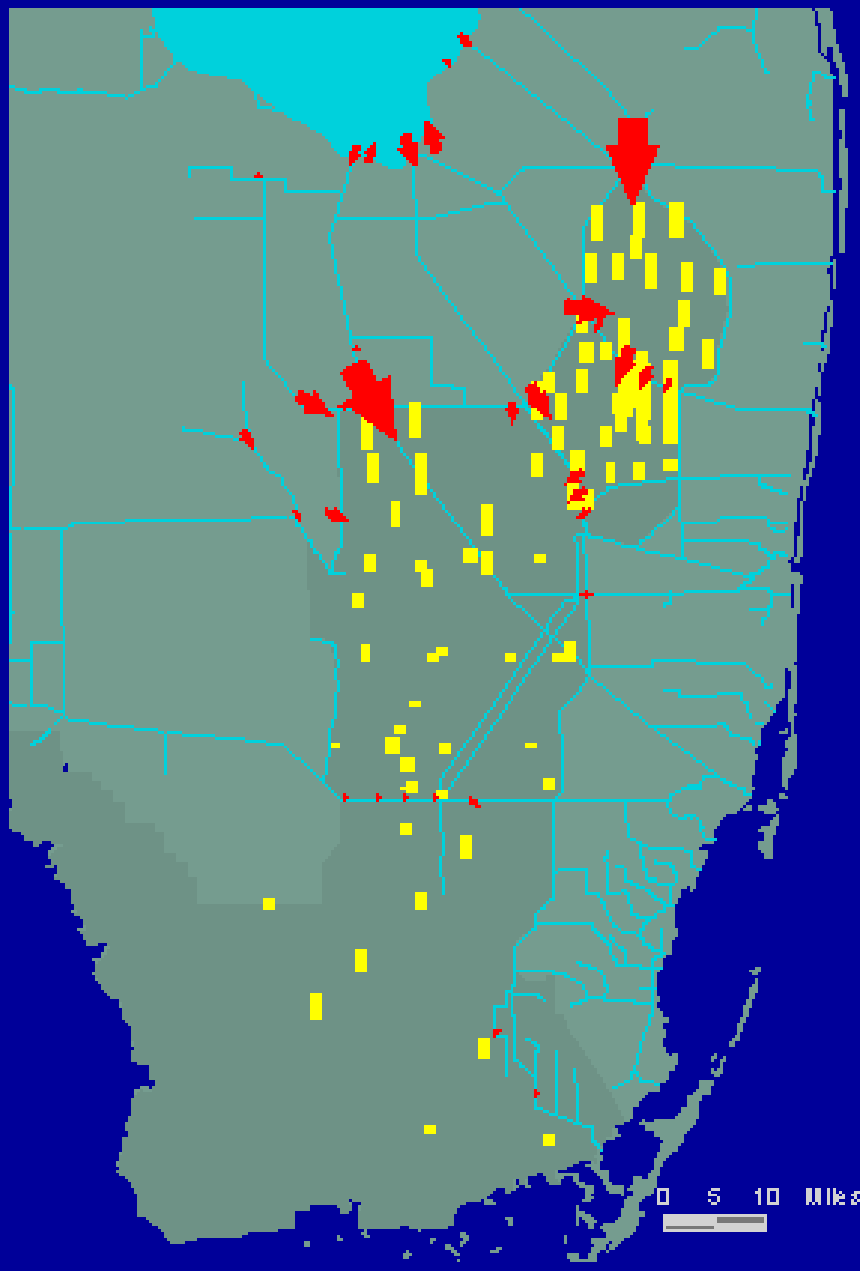
Florida TP Criterion = 10 ppb



Structure TP Loads
WY 1978 - 1991

Flow-Weighted-Mean P Concentrations
Water Years 1978-1991 vs. 1992-1996





Structure TP Loads

&

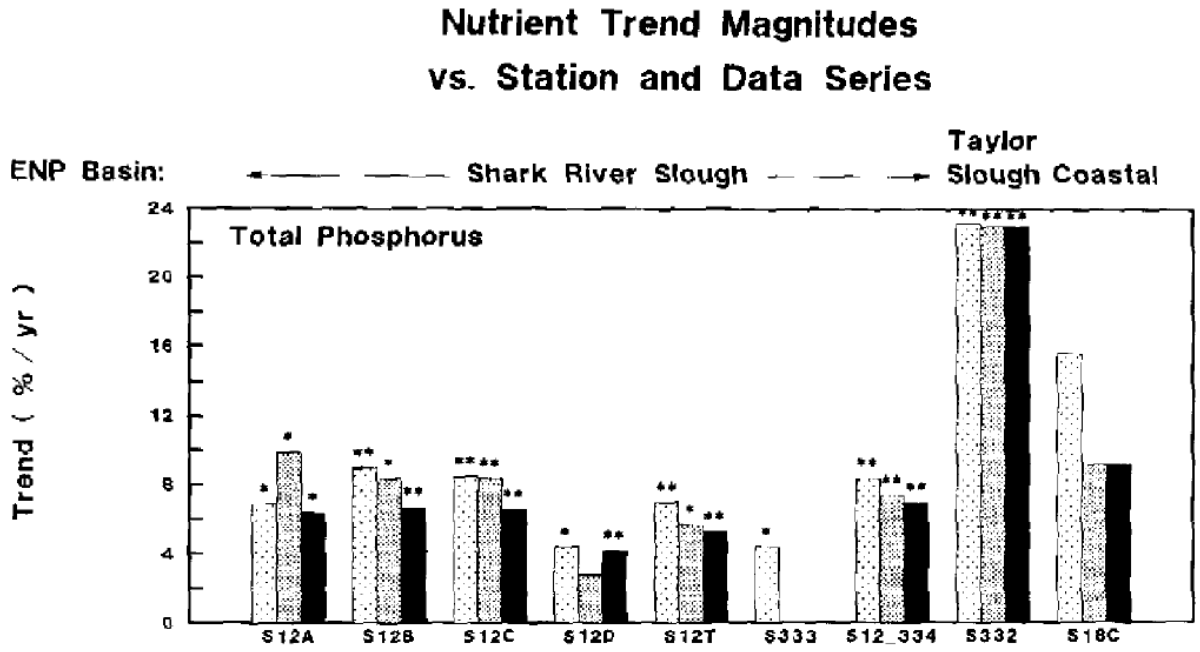
Marsh Frequencies
TP > 10 ppb

WY 1978 - 1991

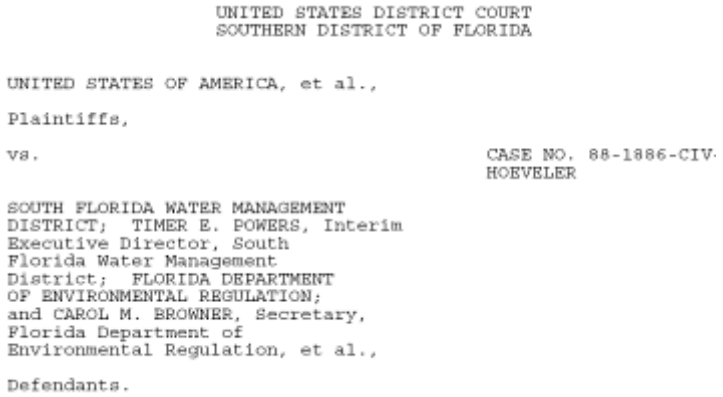
WATER QUALITY TRENDS AT INFLOWS TO EVERGLADES NATIONAL PARK[1]

William W. Walker[2]

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



Legal Remedy



UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF FLORIDA

UNITED STATES OF AMERICA, et al.,

Plaintiffs,

vs.

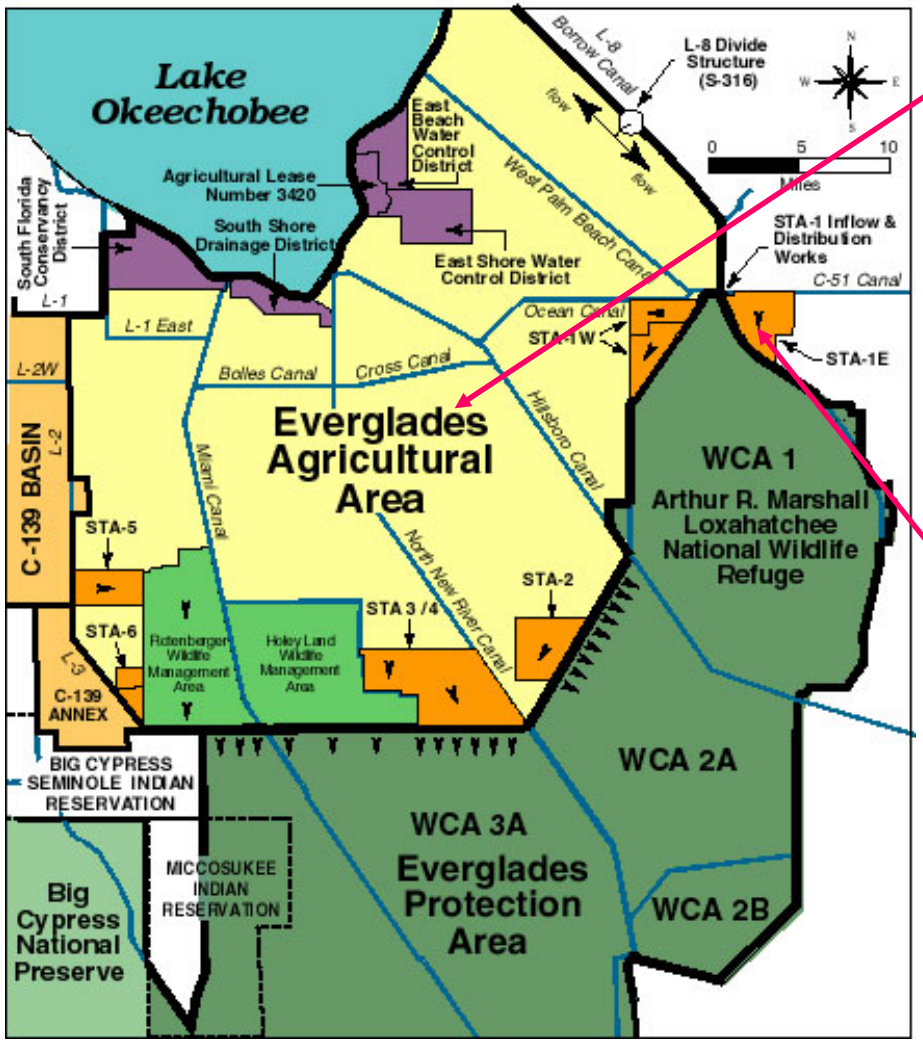
CASE NO. 88-1886-CIV-
HOEVELER

SOUTH FLORIDA WATER MANAGEMENT
DISTRICT; TIMER E. POWERS, Interim
Executive Director, South
Florida Water Management
District; FLORIDA DEPARTMENT
OF ENVIRONMENTAL REGULATION;
and CAROL M. BROWNER, Secretary,
Florida Department of
Environmental Regulation, et al.,

Defendants.

- Federal Lawsuit Filed by U.S. Dept of Justice & Interior in 1988
- Nutrient Impacts Resulting for State's Failure to Enforce Water Quality Standards
- Two-Phase Control Program Established in 1991 Settlement Agreement
- Phase I to be Completed by 2001
  - Best Management Practices (BMPs) to Reduce Farm Runoff P Loads by 25%
  - Wetland Stormwater Treatment Areas (STAs) to Reduce Marsh Inflows to 50 ppb
  - Achieve 80% Overall Reduction in P Load vs. 1979-1988 Conditions
  - Restore Federal Waters to 1978-1979 Conditions
    - Loxahatchee Refuge Marsh Sites (WCA-1)
    - Everglades National Park Inflows
  - Research to Establish P Criterion for Protecting Native Everglades (~ 10 ppb)
- Phase II to be Completed by December 2006 [Current Projection >? 2016 ?]
  - Implement Additional Control Technology (BMPs, STAs, etc.)
  - Achieve Compliance with P Criterion Throughout the Everglades Marsh (10 ppb)
  - Achieve More Stringent P Criteria in Loxahatchee Marsh and ENP Inflows (6 – 8 ppb)

Phase I Control Program



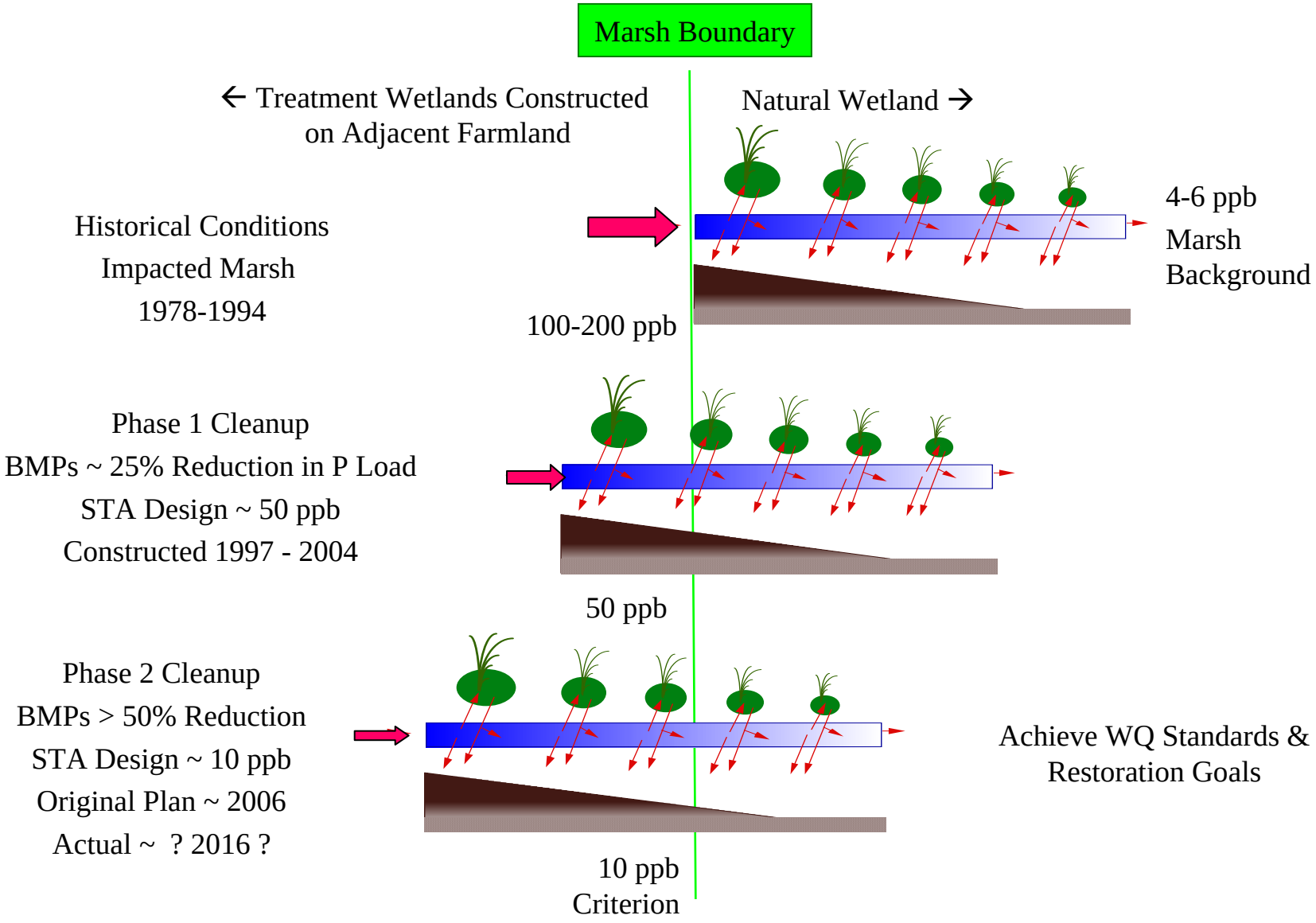
Agricultural BMPs

Regulatory Program
25% Reduction in Total Runoff Load
~250 Farms on ~500,000 acres
Implemented 1995
Cost < $0 ???
Achieving ~50% Reduction Overall

Stormwater Treatment Areas (STAs)

50 ppb Interim Design Target
~43,000 Acres
Constructed 1994 – 2004
Cost ~$700 Million
Achieving 20 – 100 ppb

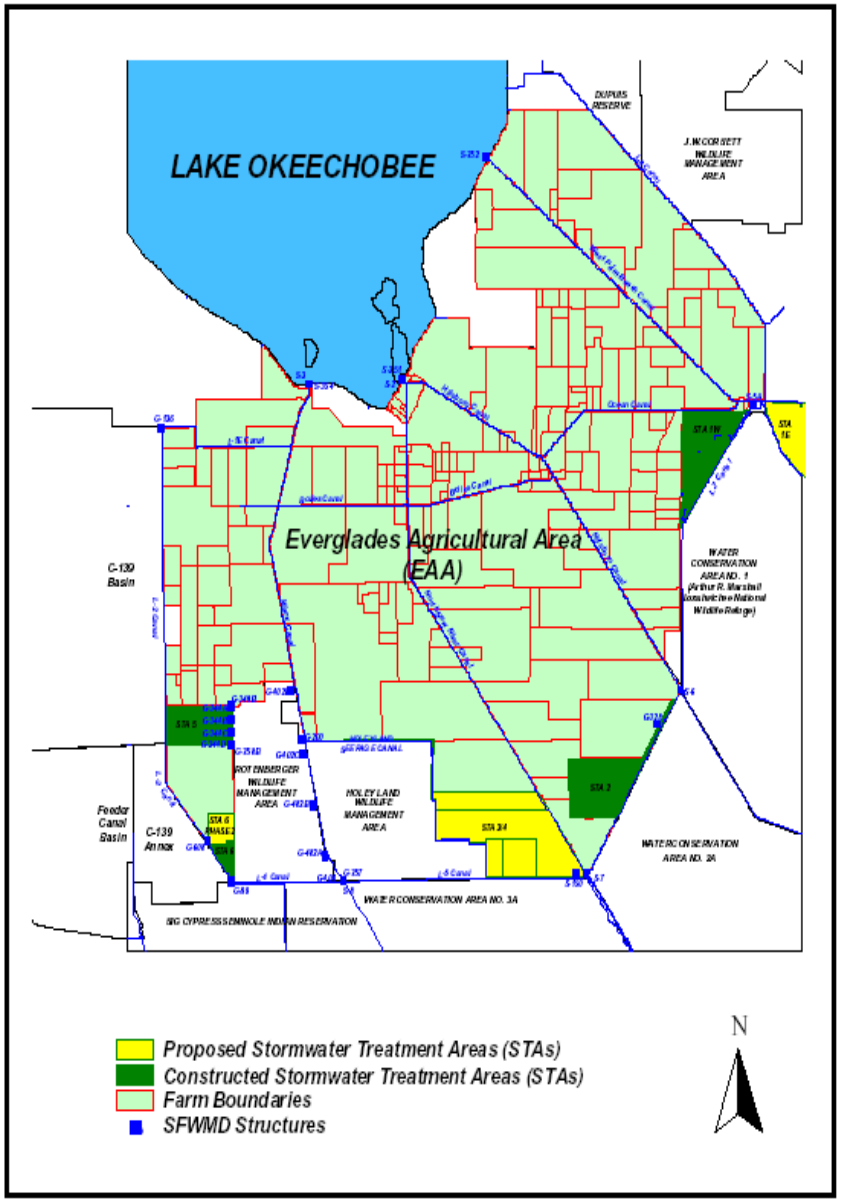
Displacement of P Gradient With Implementation of P Controls



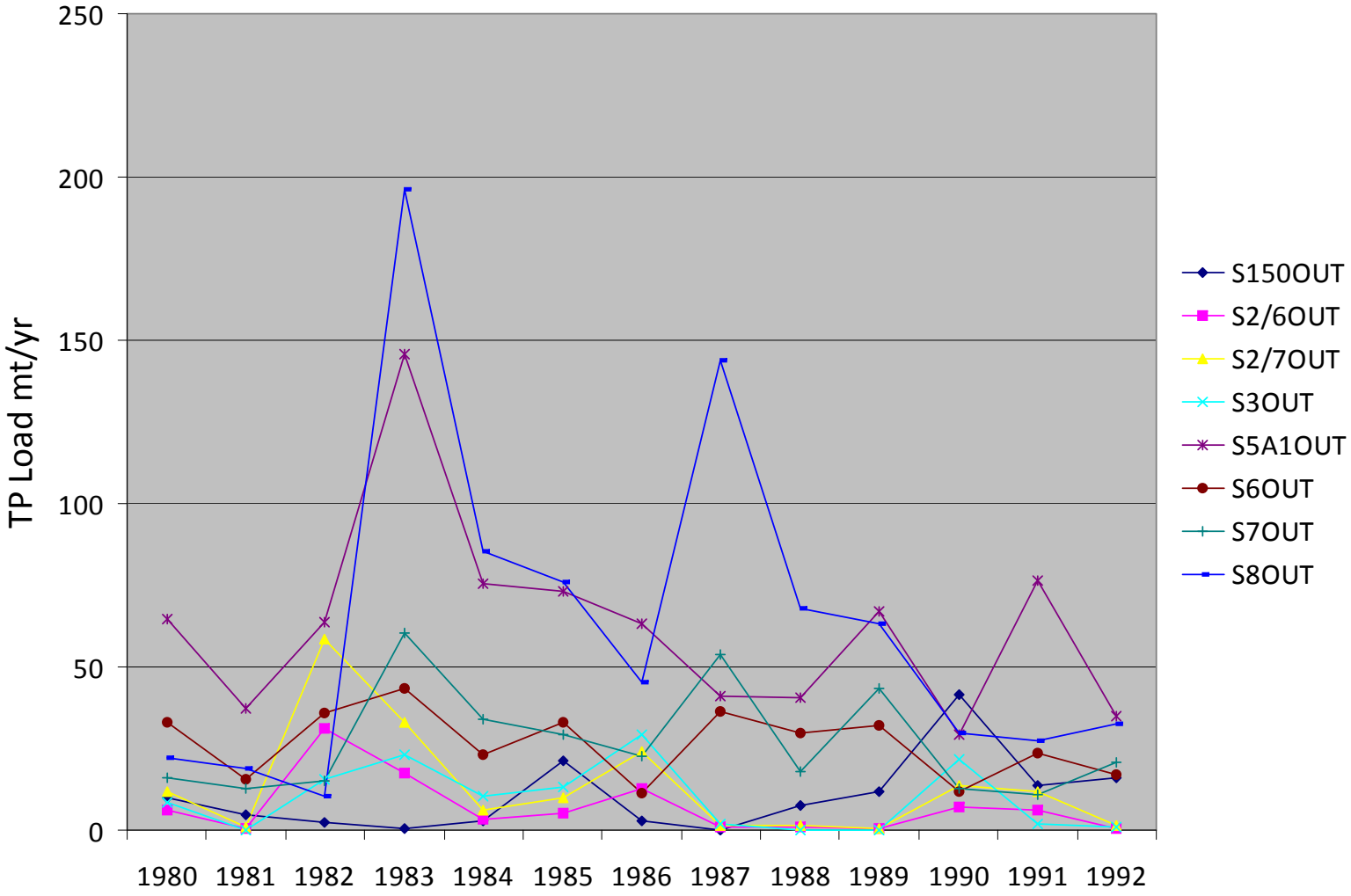
Evaluating Performance of Best Management Practices (BMPs) to Reduce P Loads in Farm Runoff

EVERGLADES
BEST MANAGEMENT PRACTICES
PROGRAM
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

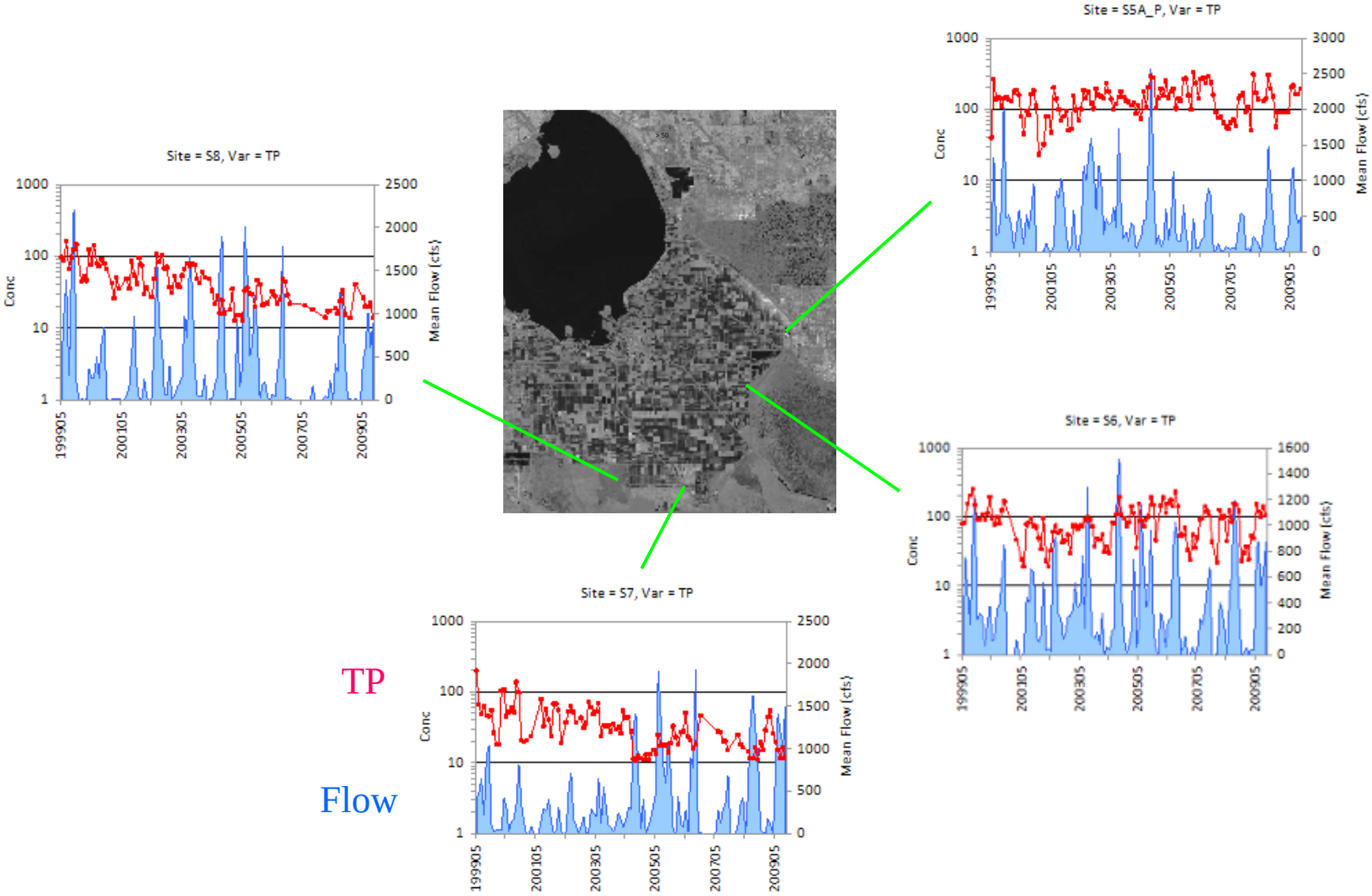
- Basin Area ~500,000 Acres
- Objectives
    - Implement BMP's!
    - 25% Reduction in Basin P Load
    - 1979-1988 Baseline
- Regulatory Rule Effective 1995
- Monitoring Program
    - Farm Inspections
    - Weekly Composite Sampling
    - Basin-Scale ~35 Sites
    - Farm-Scale ~200 Sites



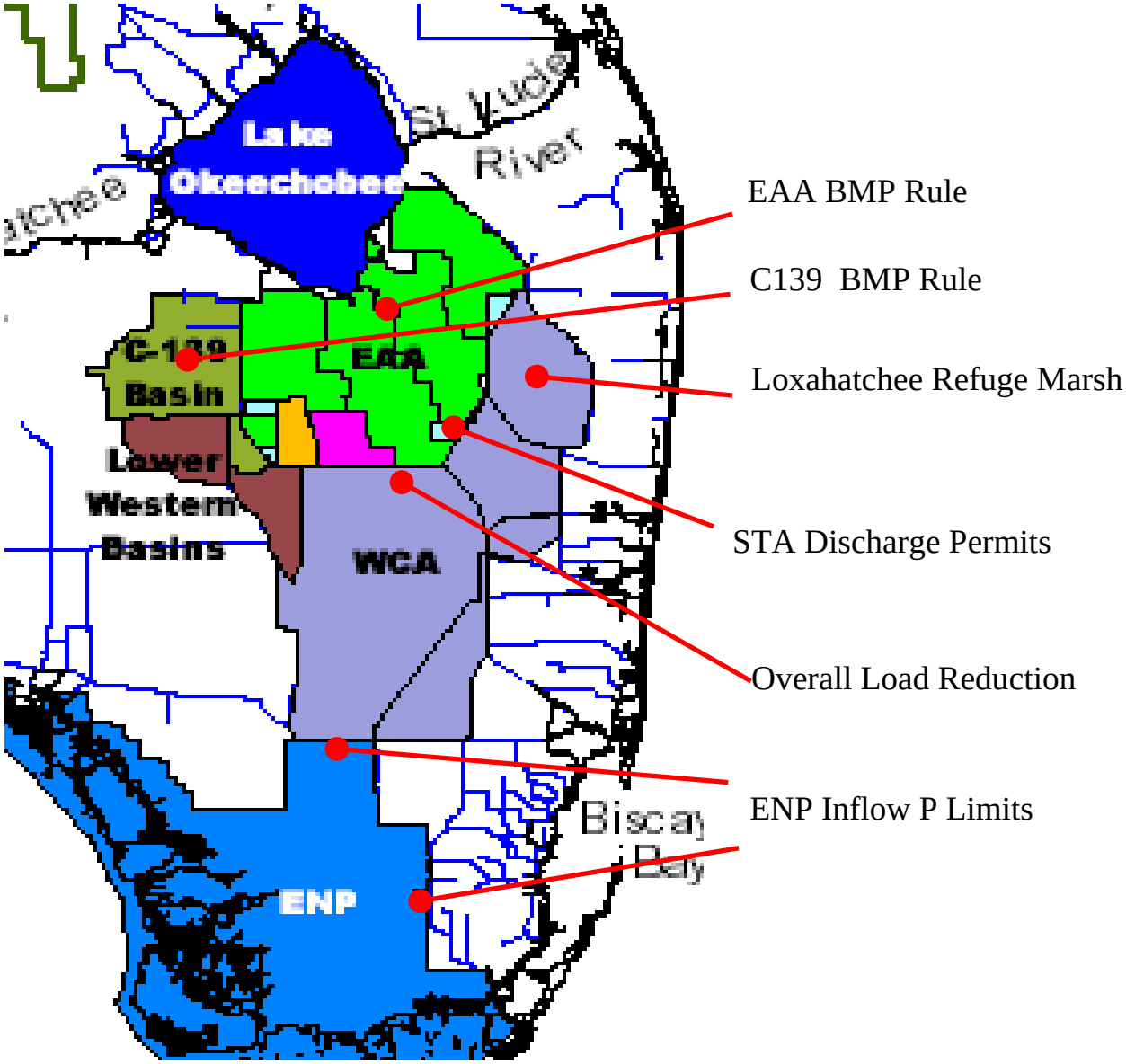
TP Load in EAA Outflows, 1980-1992
How to Measure a 25% Reduction?



Monthly Outflows & TP Concentrations at 4 Major EAA Pump Stations, 2000-2009



Statistical Models For Measuring Progress & Compliance



Statistical Models for Measuring Long-Term Changes Due to Management

Sources of Variation in Yearly Time Series:

- Change in Long-Term Mean Due to Management Measures
- Hydrologic Variations (Rainfall, Flow, Water Level)
- Random (Natural, Measurement)

Multiple Regression Models Used to Factor Out Hydrologic Variability in Yearly Data

Fit to Long-Term Datasets Collected Prior to Implementation of Controls

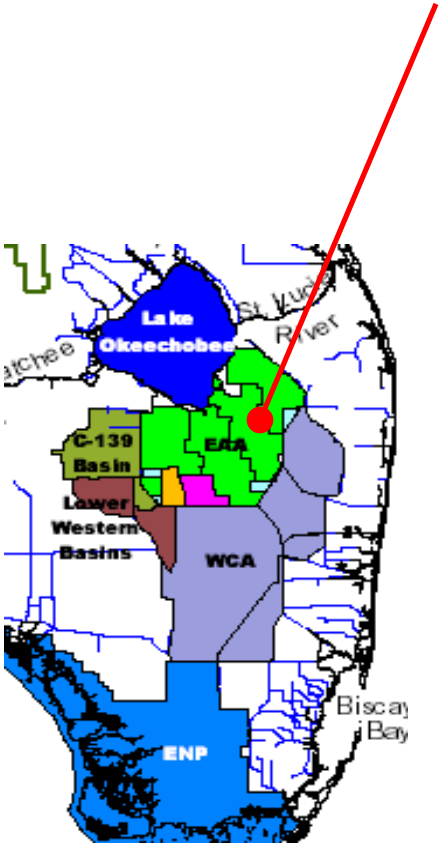
Test Null Hypothesis: Management Objective Has Been Achieved

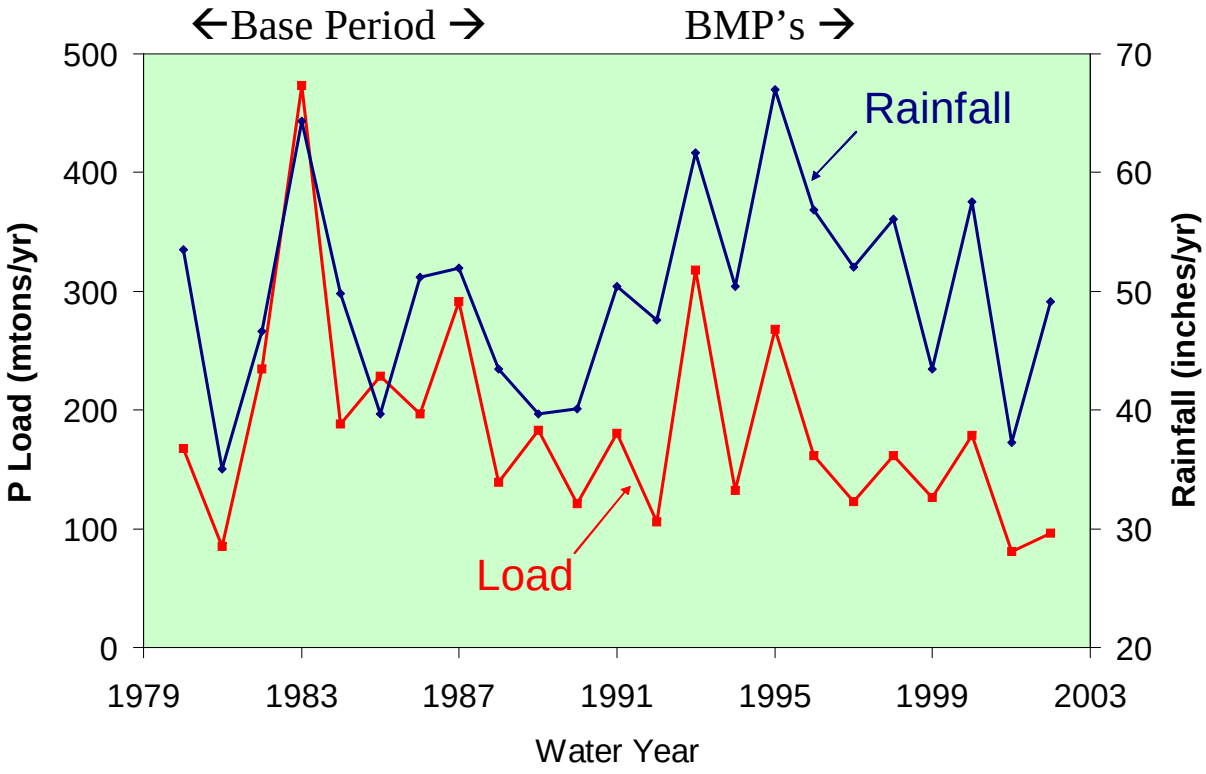
Reject if Future Data Exceed 90^{th} Percentile of Predicted Value in Any Year

Compare Data with "Target Zone" (10-90^{th} Percentiles) to Measure Progress

Used to Determine Compliance with Consent Decree and Regulatory Rules

Tracking EAA Total P Loads



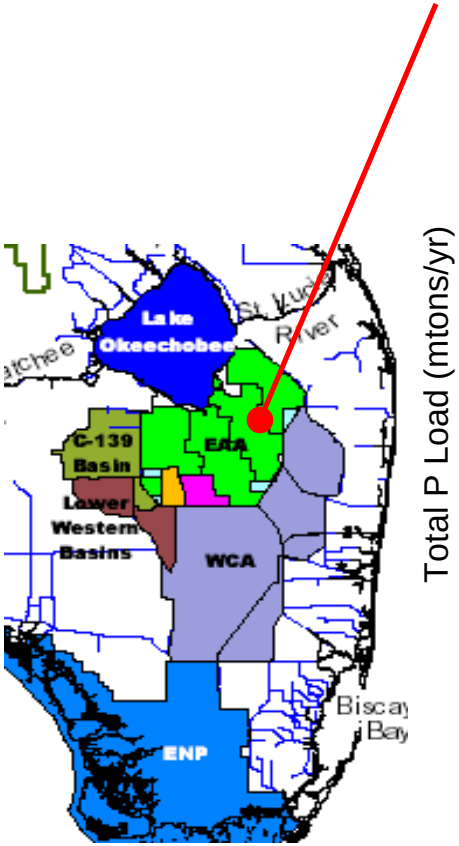


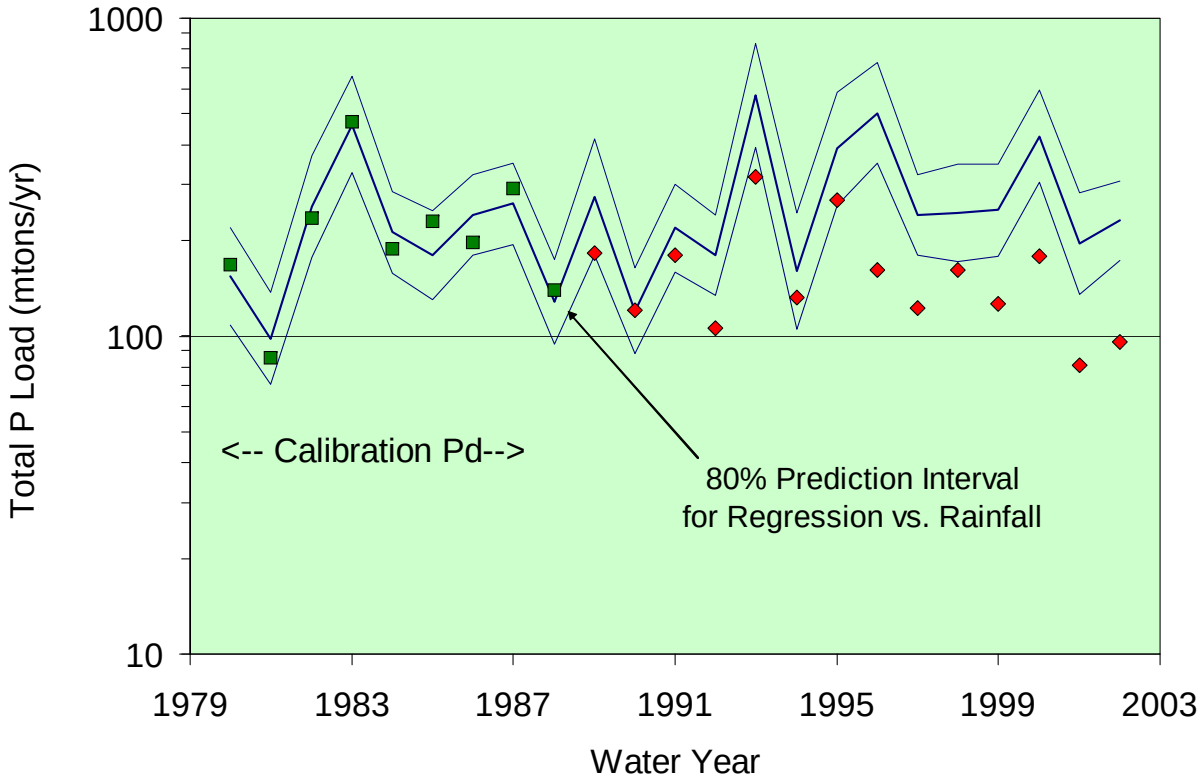
Model:

TP Load = Reduction + Rainfall-Effect + Random

Objective: 25% Load Reduction vs. 1979-88

Tracking EAA Total P Loads



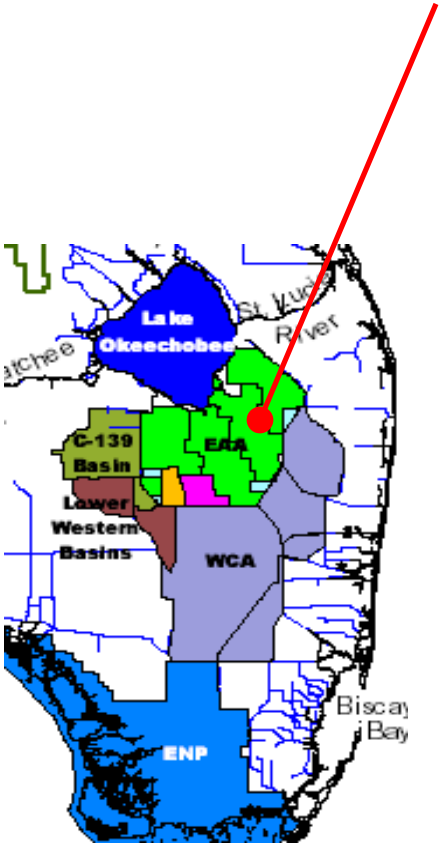


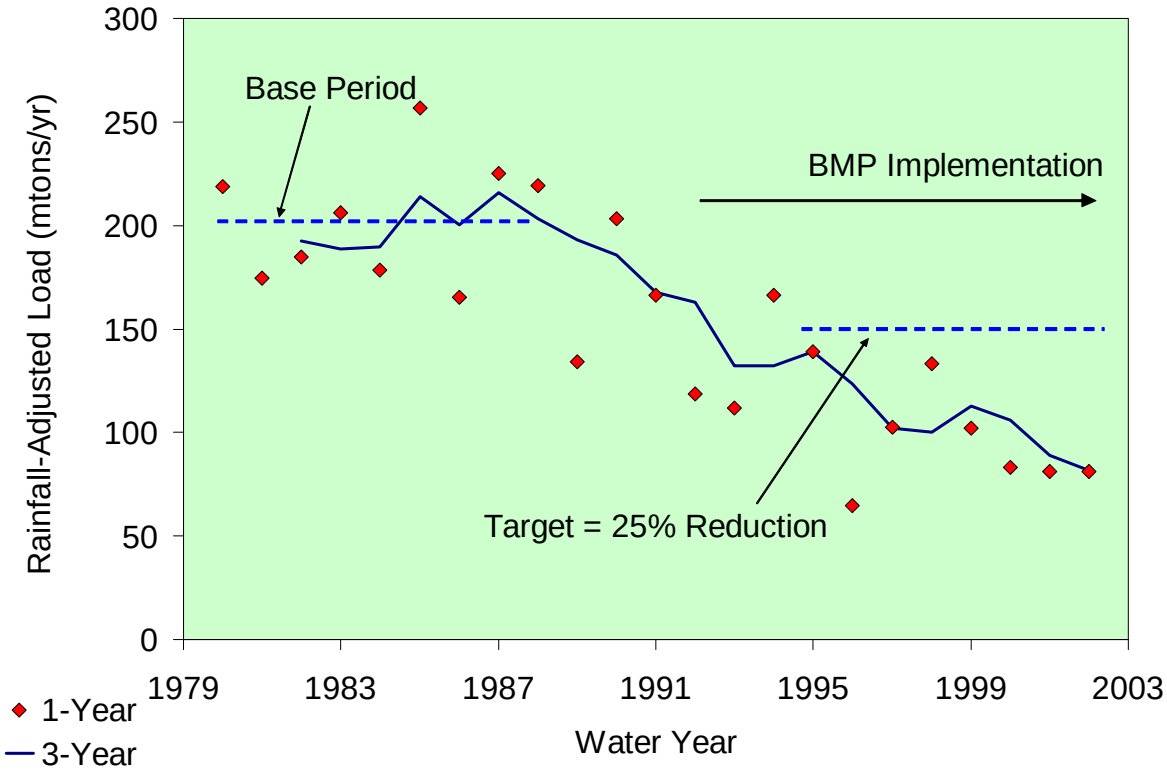
Model Calibration: $R^2 = 0.91$

TP Load = Reduction + Rainfall-Effect + Random

Objective: 25% Load Reduction vs. 1979-88

Tracking EAA Total P Loads



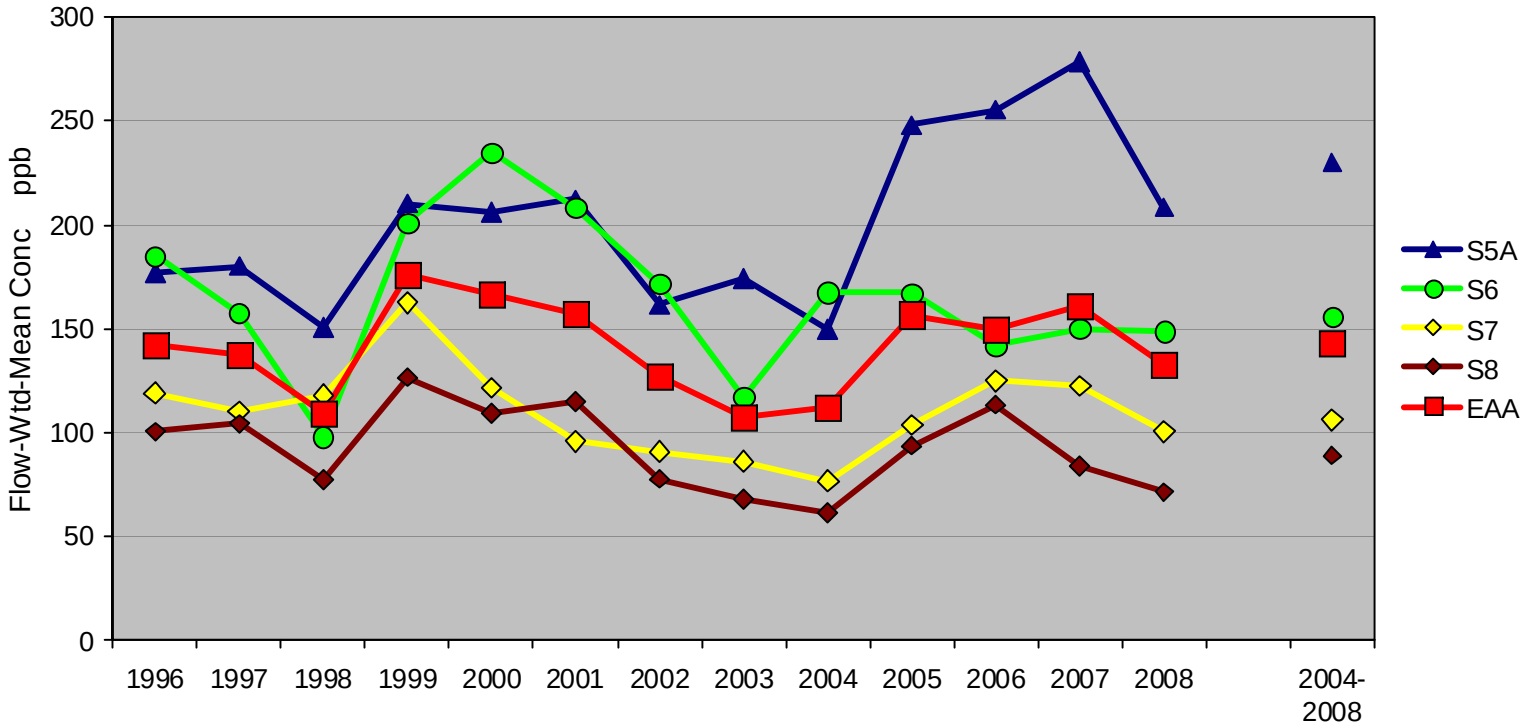


TP Loads Adjusted to Average Rainfall

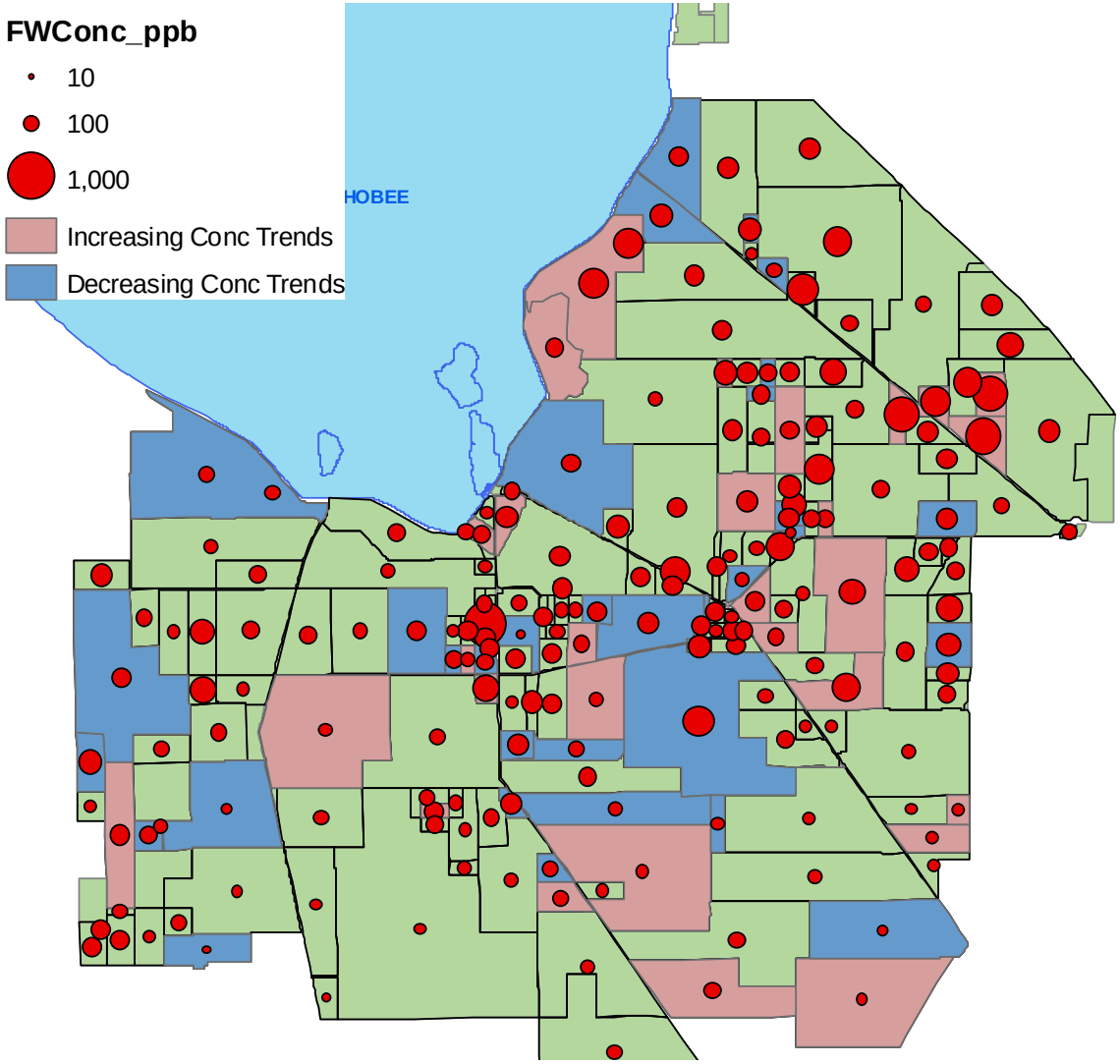
Objective: 25% Load Reduction vs. 1979-88

Trends in EAA Farm Monitoring Data by Basin

Runoff FWM Concentration



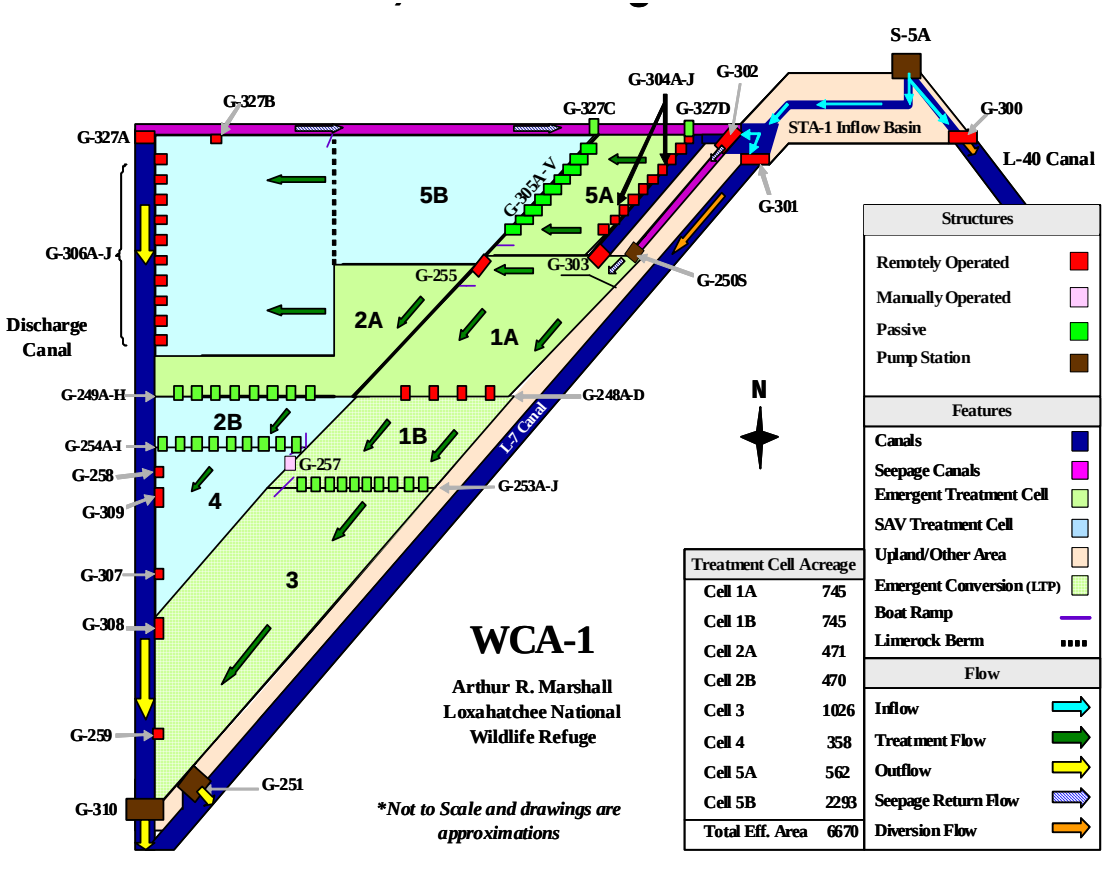
TP Concentrations & Trends in Runoff from Individual Farms



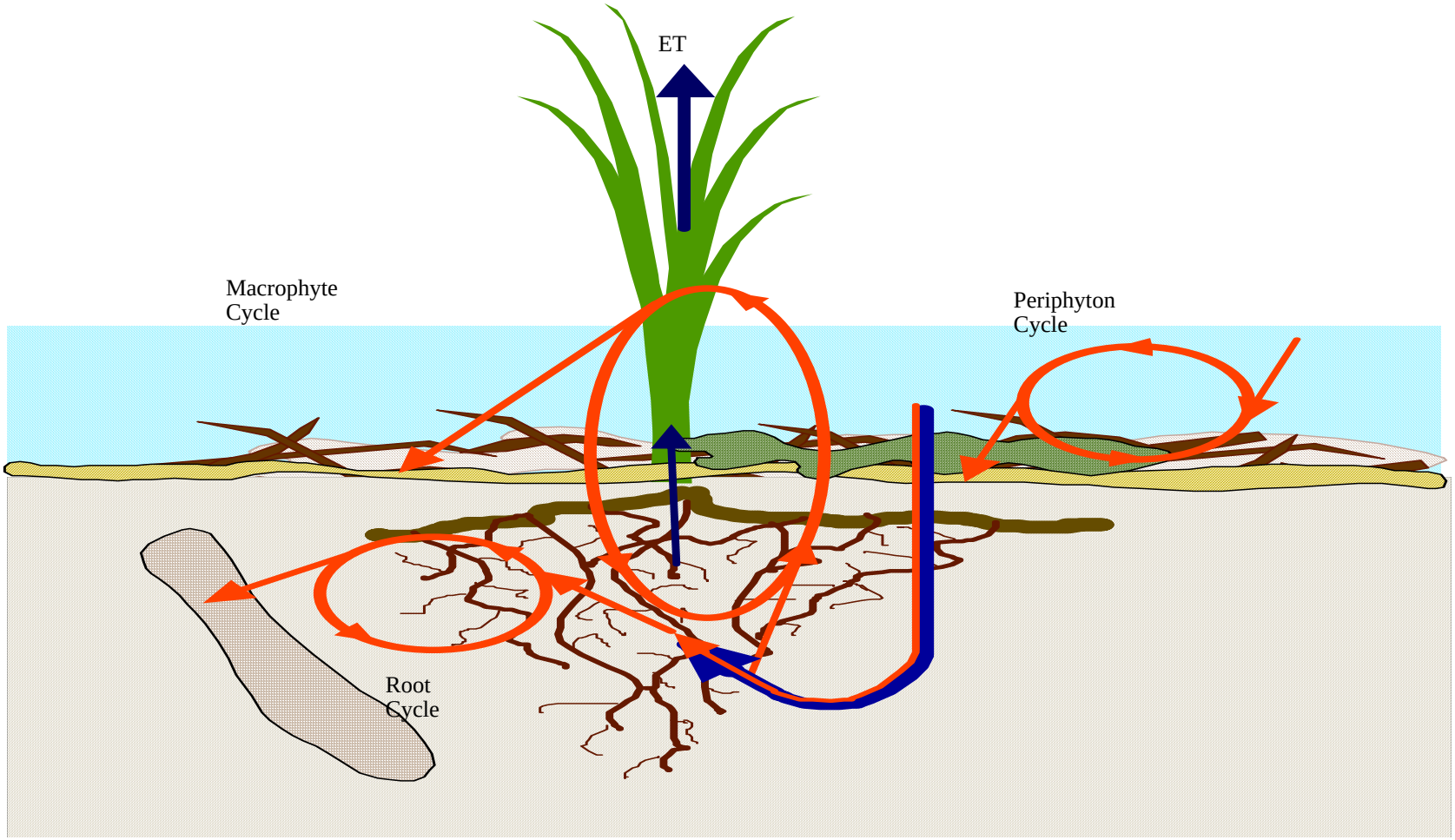
Modeling to Support Design of Wetland Stormwater Treatment Areas (STAs)

- Acreage Required to Meet Outflow P Targets
- Optimization
  - Vegetation
  - Hydraulics
- Forecasting Long-Term STA Performance
- Forecasting Downstream Marsh Responses

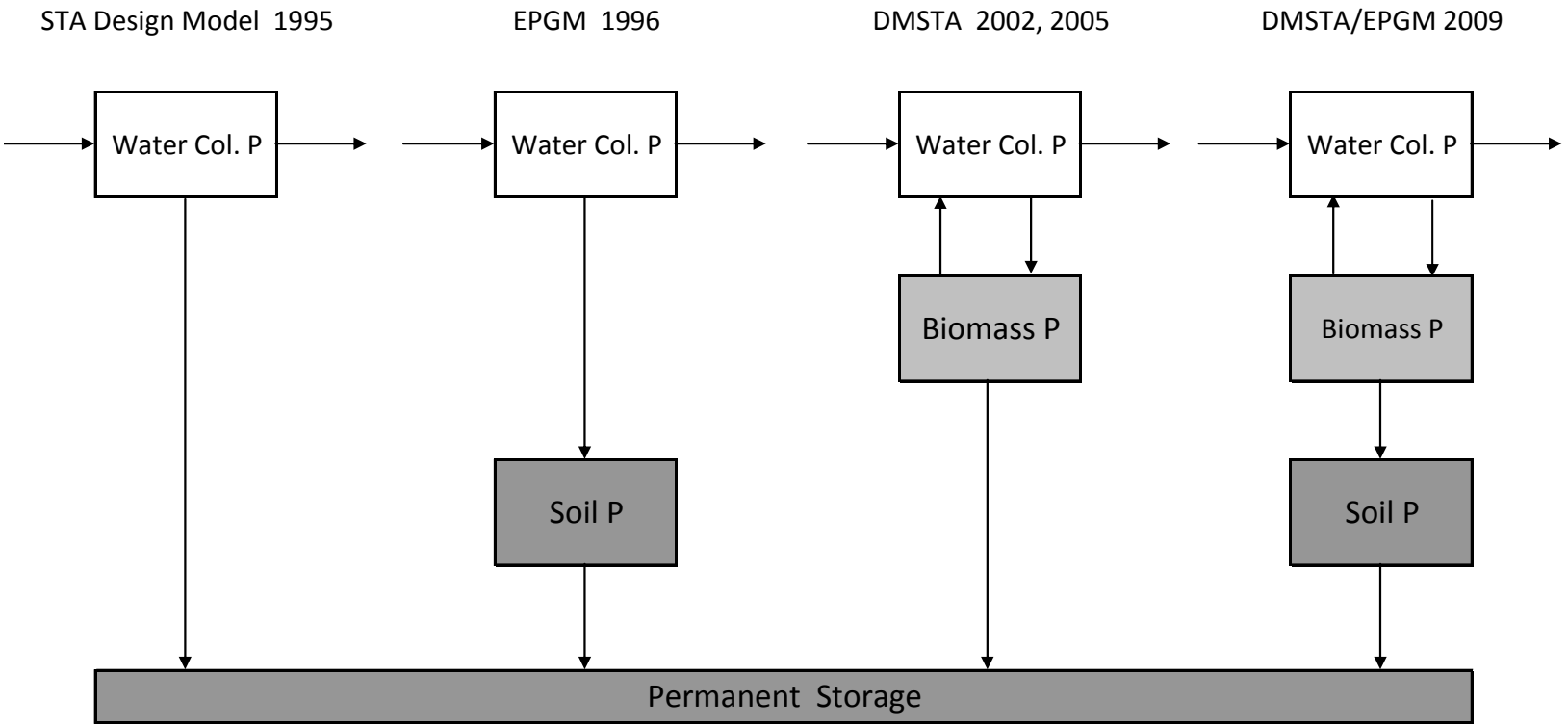
Stormwater Treatment Area 1 West
Constructed 1994-1999 Area 6,670 acres



Biological Cycling



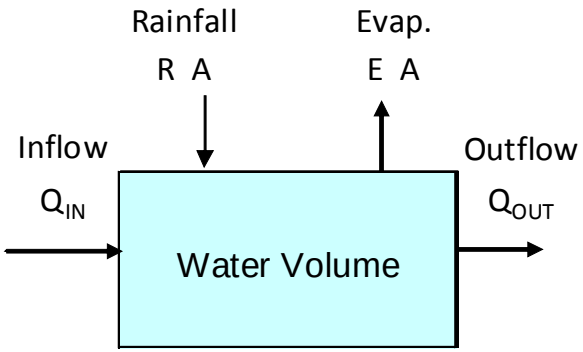
Phosphorus Models for Everglades Applications

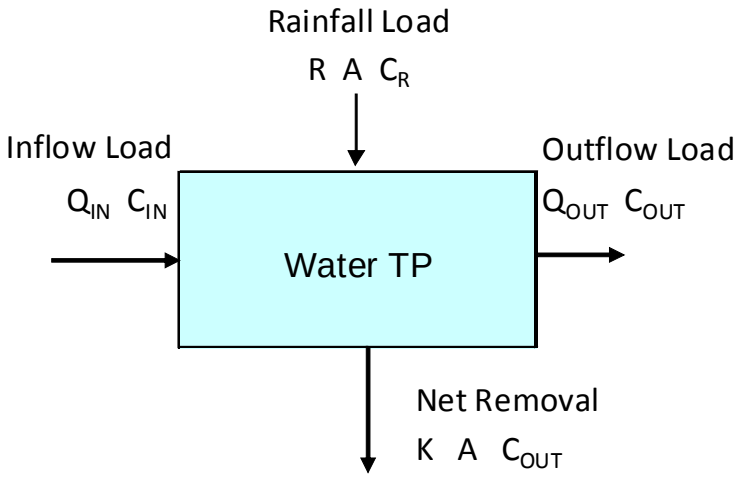


Phosphorus Balance Models

- Engineering-Oriented
- Aggregated Variables & Processes
- Limited Input Data & Calibration Requirements
- Calibrated & Tested vs. Regional Datasets
  - Experimental Platforms (Mesocosms, Test Cells, etc)
  - Natural Wetlands
  - Stormwater Treatment Areas
  - Lakes & Reservoirs
- Applicability Limited to Data Boundaries
- Uncertainty Evaluated

Water & Phosphorus Balances for One Wetland Segment





Water Balance:

Inflow = Rainfall = Outflow + Evaporation

Solution:

$$Q_{OUT} = Q_{IN} + (R - E)\,A$$

P Mass Balance:

Inflow + Rainfall = Outflow + Net Removal

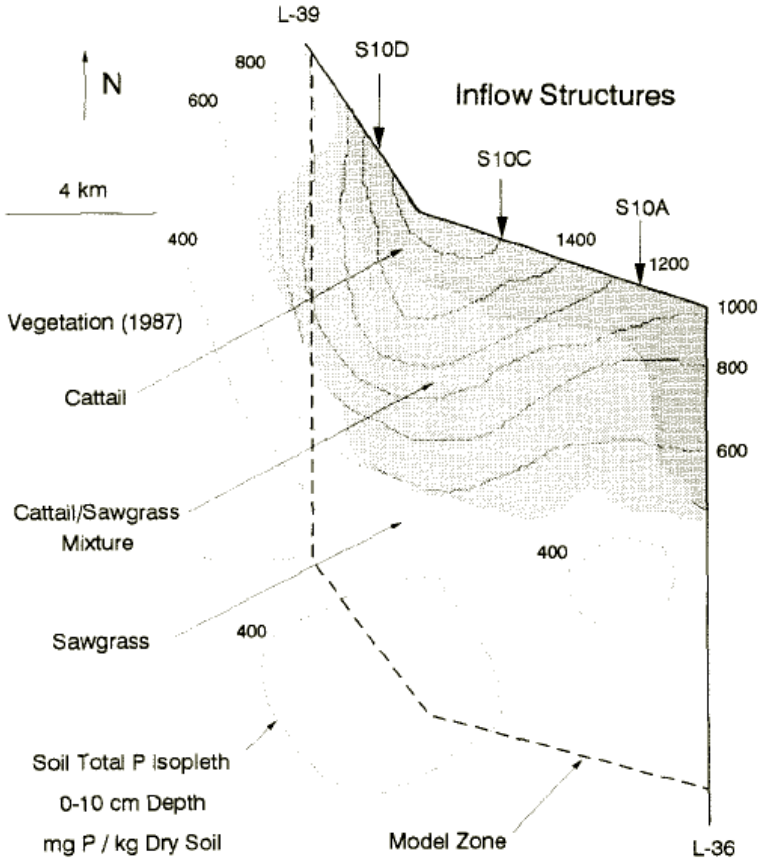
Solution:

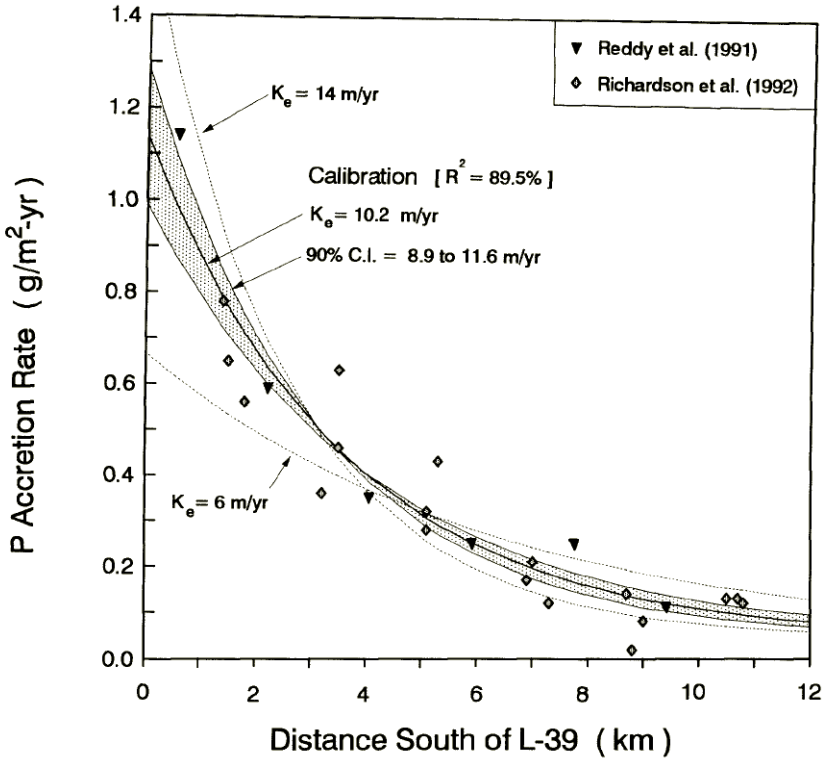
$$C_{OUT} = (Q_{IN}\,C_{IN} + R\,A\,C_R) / (Q_{OUT} + K\,A)$$

Terms:

Q	Flow Rate	10^6 m^3 / yr	Inflow Measured, Outflow Predicted
A	Area	10^6 m^2	Specified Design
C	TP Concentration	mg/m^3	Inflow & Rainfall Measured, Outflow Predicted
R	Rainfall	m/yr	Measured
E	Evapotranspiration	m/yr	Measured
K	Net P Settling Rate	m/yr	Calibrated Parameter ~ 10 m/yr

Calibration of STA Design Model - 1994





Initial STA Designs (50 ppb)

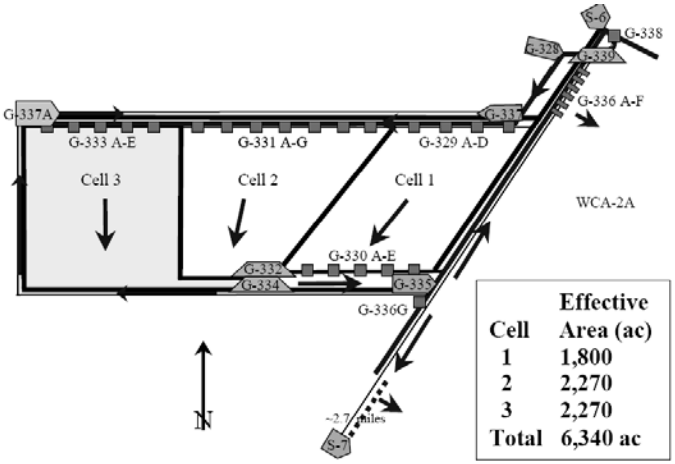


Figure 2.8 Schematic of Existing STA-2

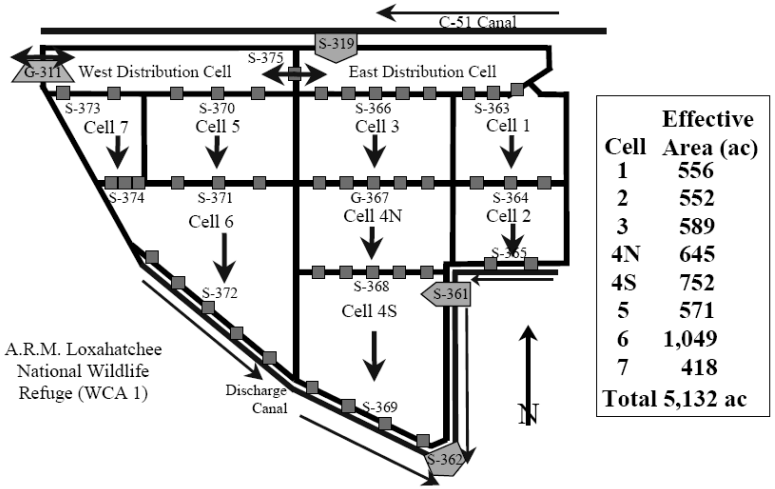


Figure 2.2 Current Design Schematic, STA-1E

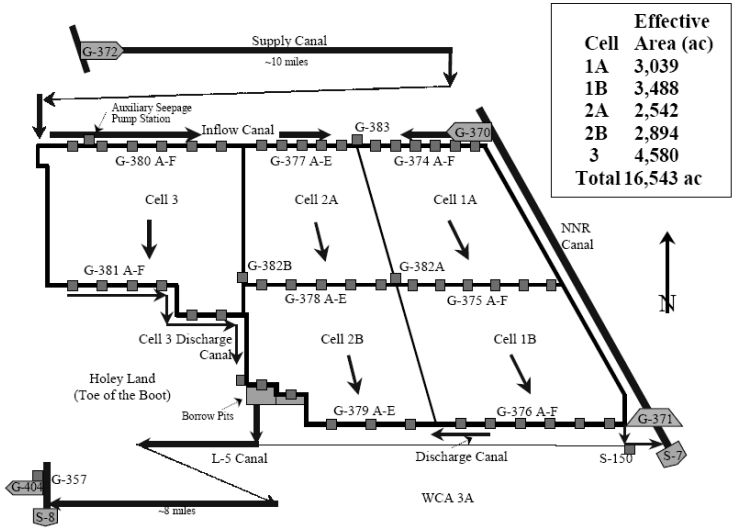


Figure 2.11 Current Design Schematic, STA-3/4

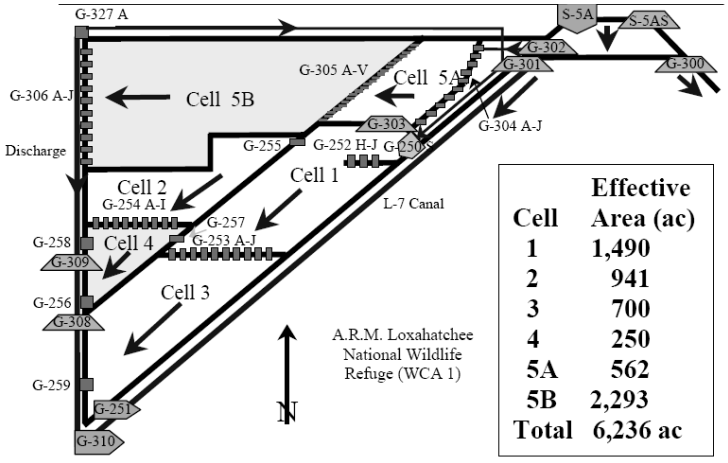
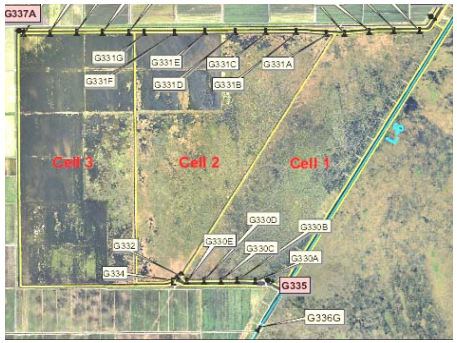
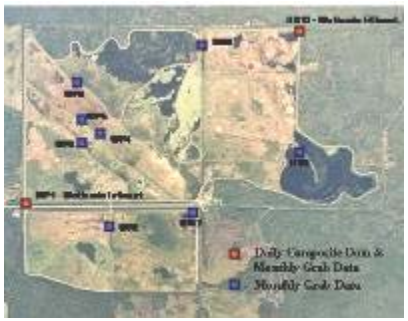


Figure 2.5 Schematic of Existing STA-1W

> 80 Platforms Used in Calibration & Testing

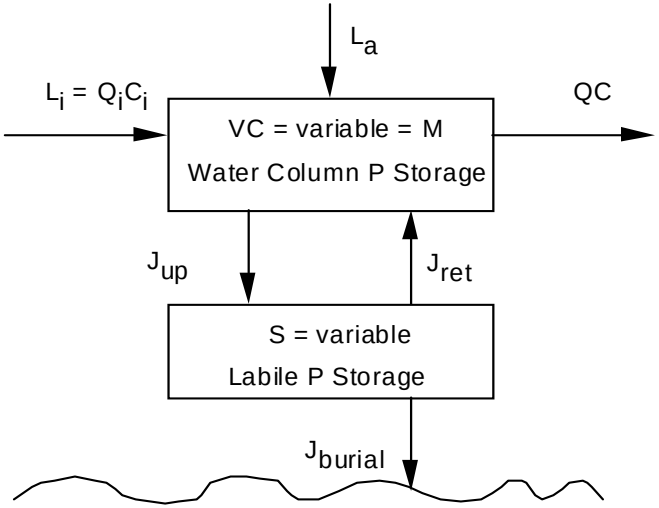
Daily Water & P Balances, .01-150 km^2, 1-30yrs



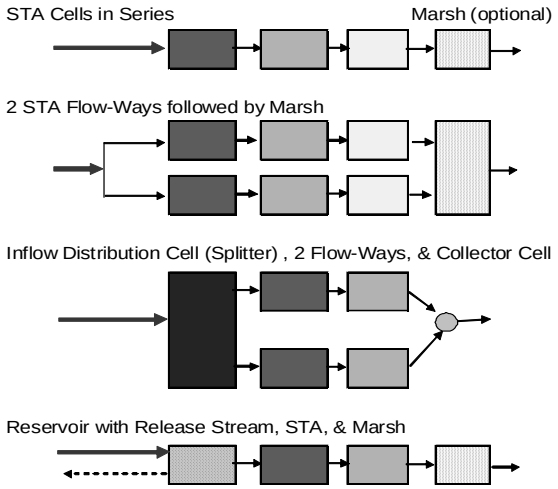


Dynamic Model for Design of Enhanced STAs

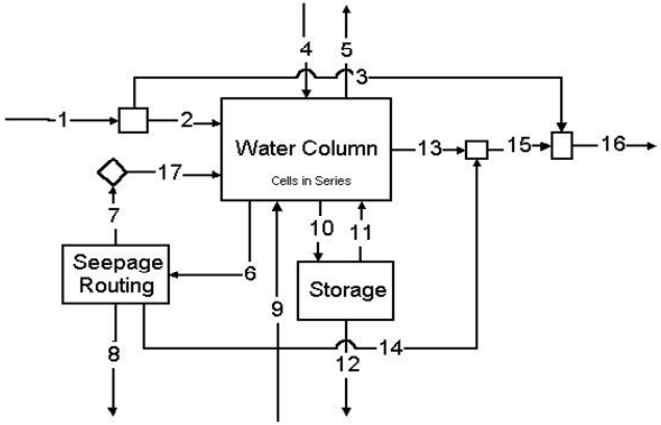
A - P Cycling Model



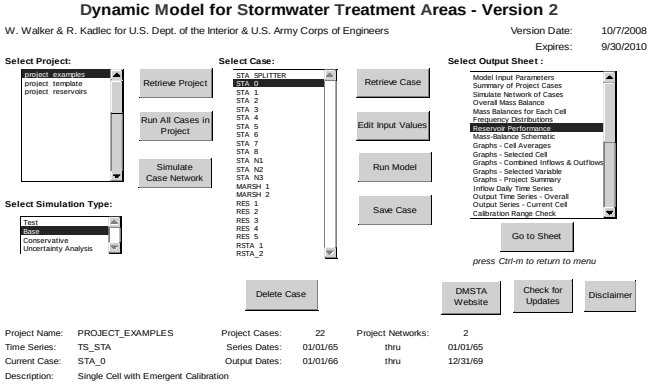
C - Cell Network Configurations



B - Hydraulic Routing Model for One Cell



D - User Interface



Treatment Area Vegetation Types

Emergent / Cattail

K ~ 10-15 m/yr

K= First-Order P Removal Rate

Enhanced P Removal

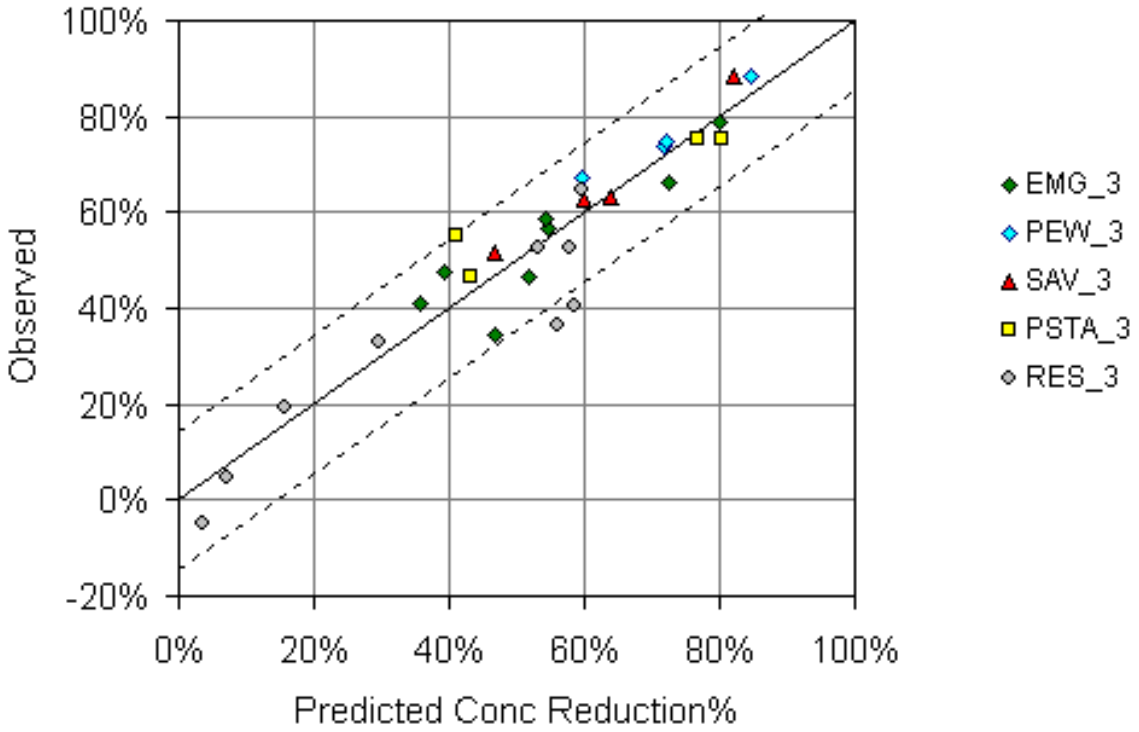
Submersed Aquatic Vegetation "SAV"

K ~ 30-60 m/yr

Periphyton / "PSTA"

K ~ 20-30 m/yr

Model Testing Using Median Calibrations for Each Vegetation Type

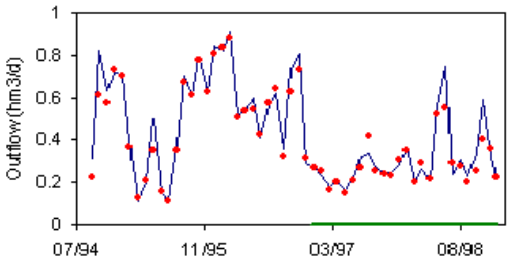


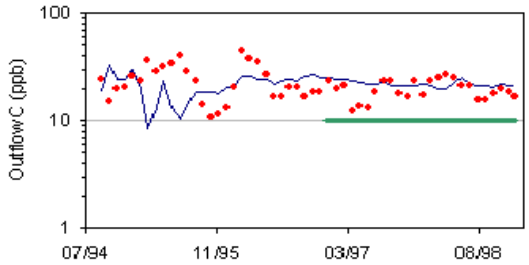
Residual Statistics				Parameter Values		
Variable	R^2	SE%	80% CL	Category	Count	K (m/yr)
Flow Wtd Conc	0.97	19%	24%	EMG_3	9	16.9
Geo Mean Conc	0.98	15%	19%	PEW_3	7	34.9
Load	0.97	21%	27%	SAV_3	4	52.5
Conc Reduction	0.76	11%	15%	PSTA_3	6	23.6
				RES_3	9	5.0

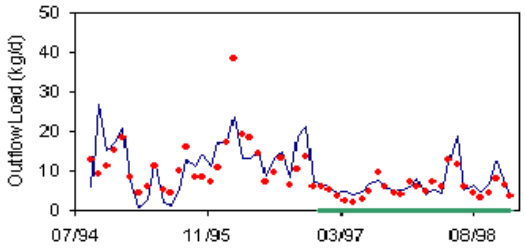
STA Simulations

Startup Period Calibration Pd

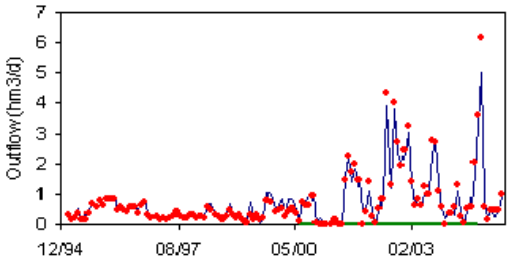
ENR Project Map Details

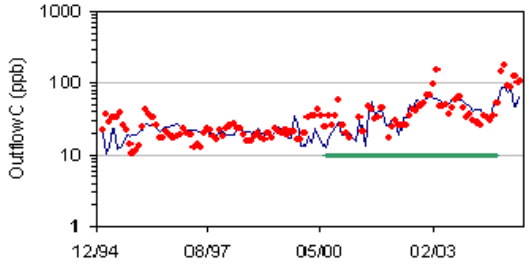


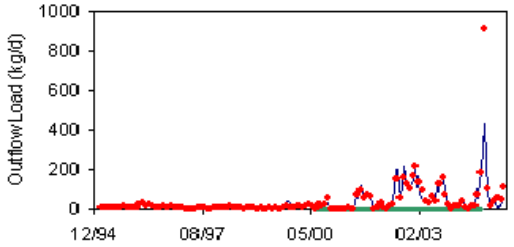




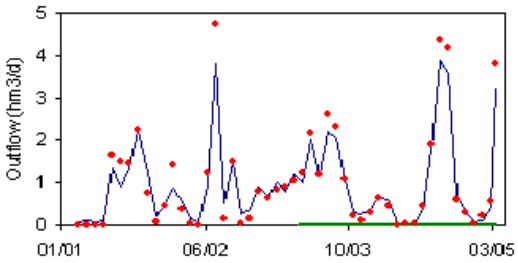
STA-1W Map Details

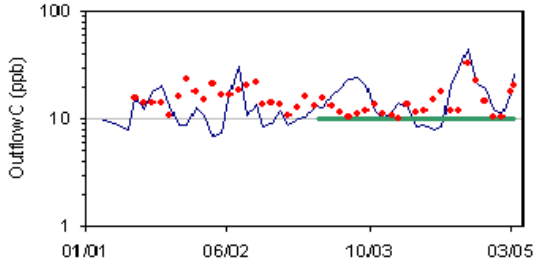


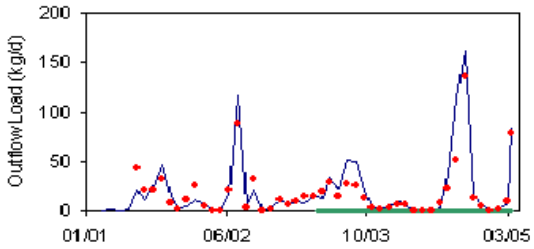




STA-2 Map Details

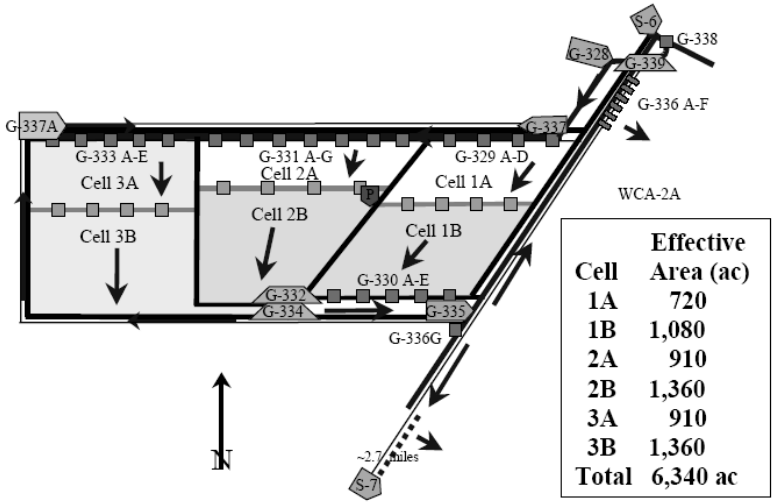






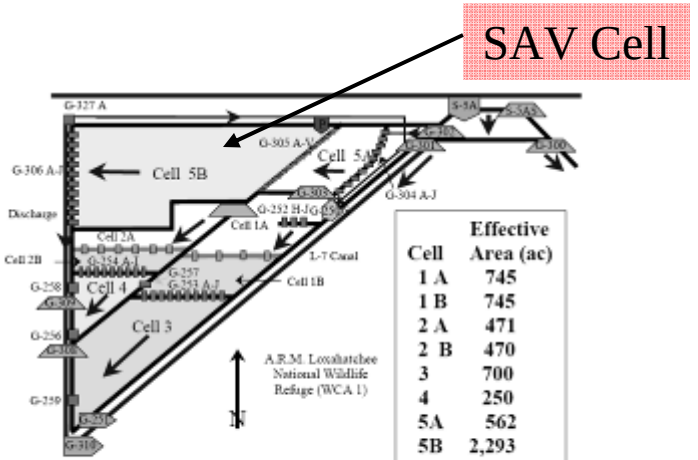
Enhanced STA Designs (? 10 - 15 ppb ?)

Predicted Response to Optimization of Vegetation & Hydraulics



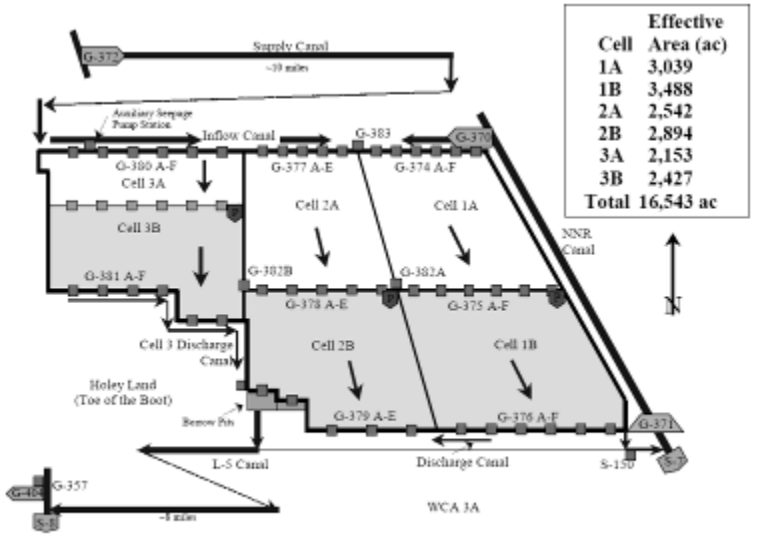
Cell	Effective Area (ac)
1A	720
1B	1,080
2A	910
2B	1,360
3A	910
3B	1,360
Total	6,340 ac

Figure 2.9 Schematic of Enhanced STA-2



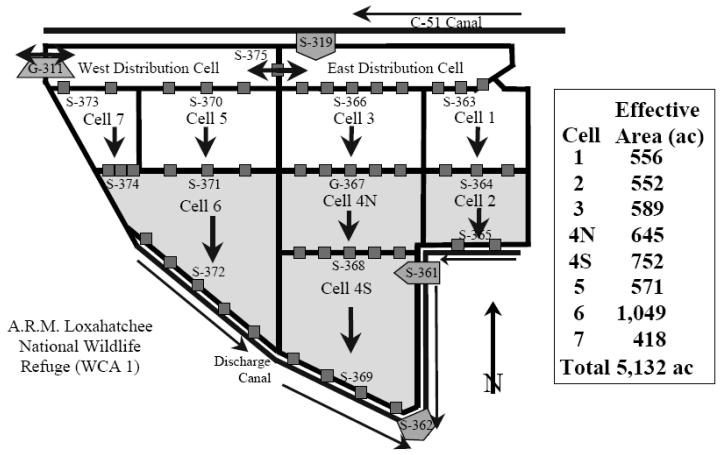
Cell	Effective Area (ac)
1 A	745
1 B	745
2 A	471
2 B	470
3	700
4	250
5A	562
5B	2,293
Total	6,236 ac

Figure 2.6 Schematic Diagram of Enhanced STA-1W



Cell	Effective Area (ac)
1A	3,039
1B	3,488
2A	2,542
2B	2,894
3A	2,153
3B	2,427
Total	16,543 ac

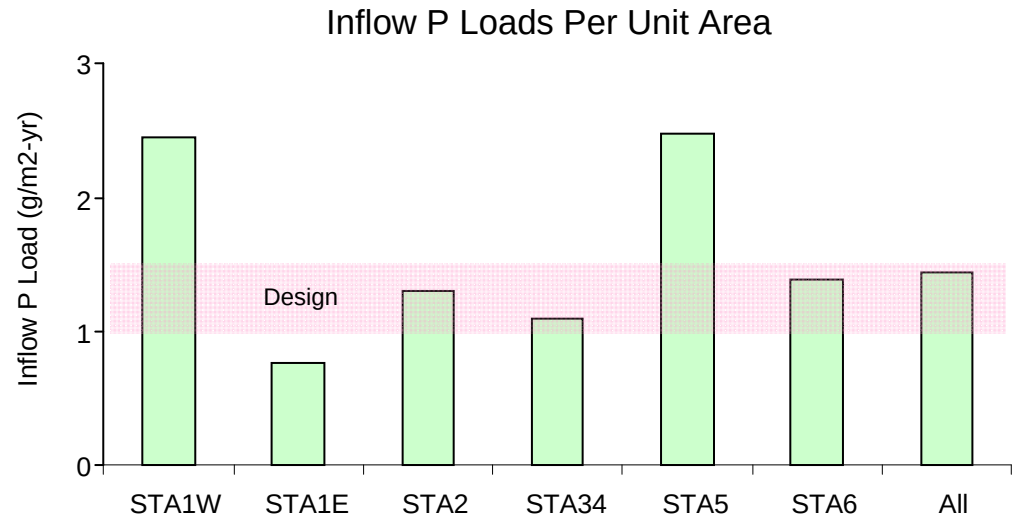
Figure 2.12 Schematic Diagram of Enhanced STA-3/4



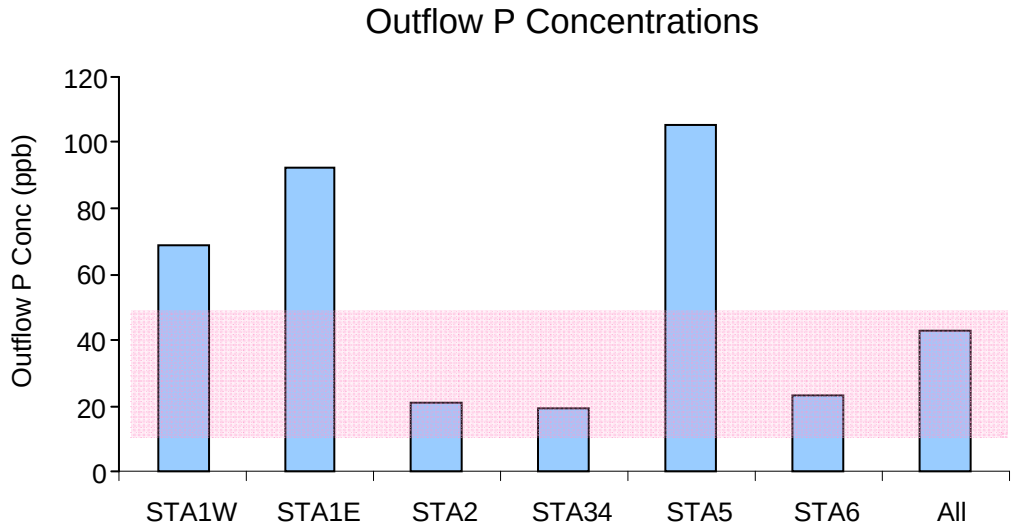
Cell	Effective Area (ac)
1	556
2	552
3	589
4N	645
4S	752
5	571
6	1,049
7	418
Total	5,132 ac

Figure 2.3 Schematic Diagram of Enhanced STA-1E

Treatment Area Performance Thru June 2007



Mean Inflow Load
Design Range

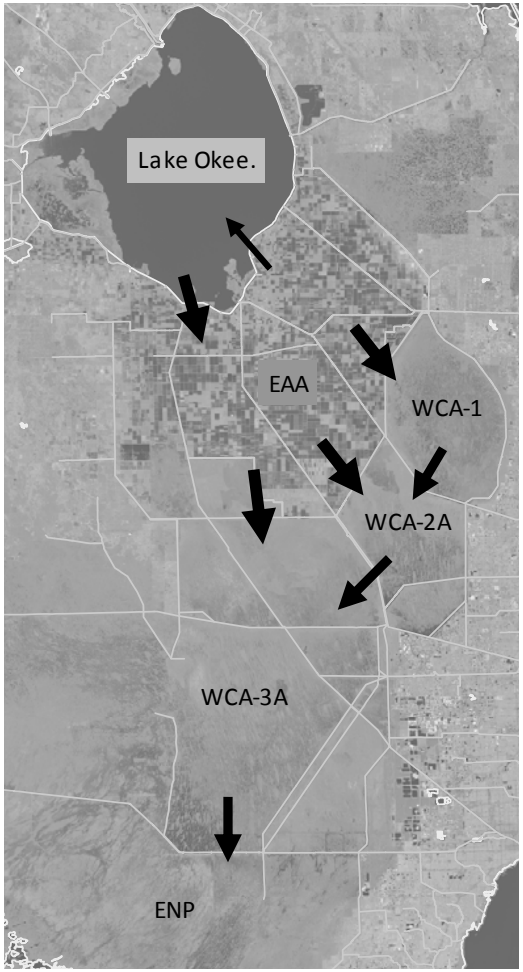


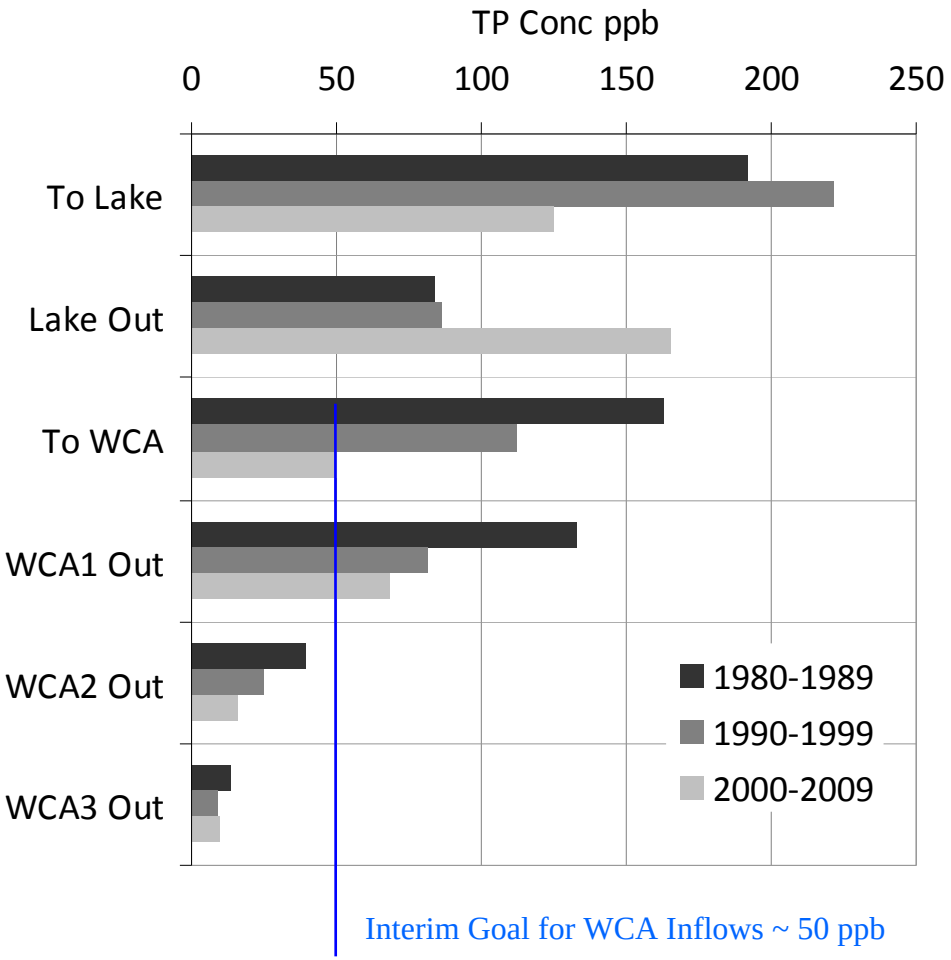
Interim Goal = 50 ppb

Long-Term Goal = 10 ppb

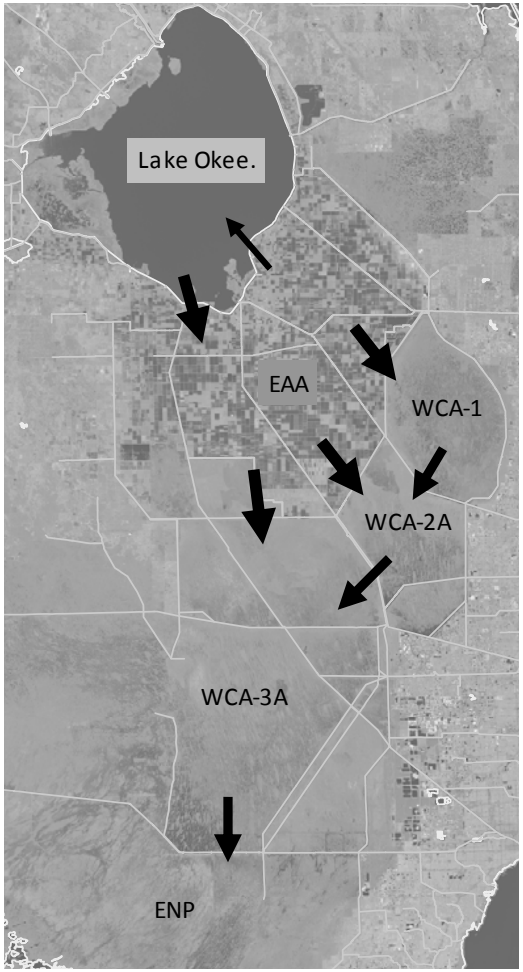
Measuring Progress & Compliance

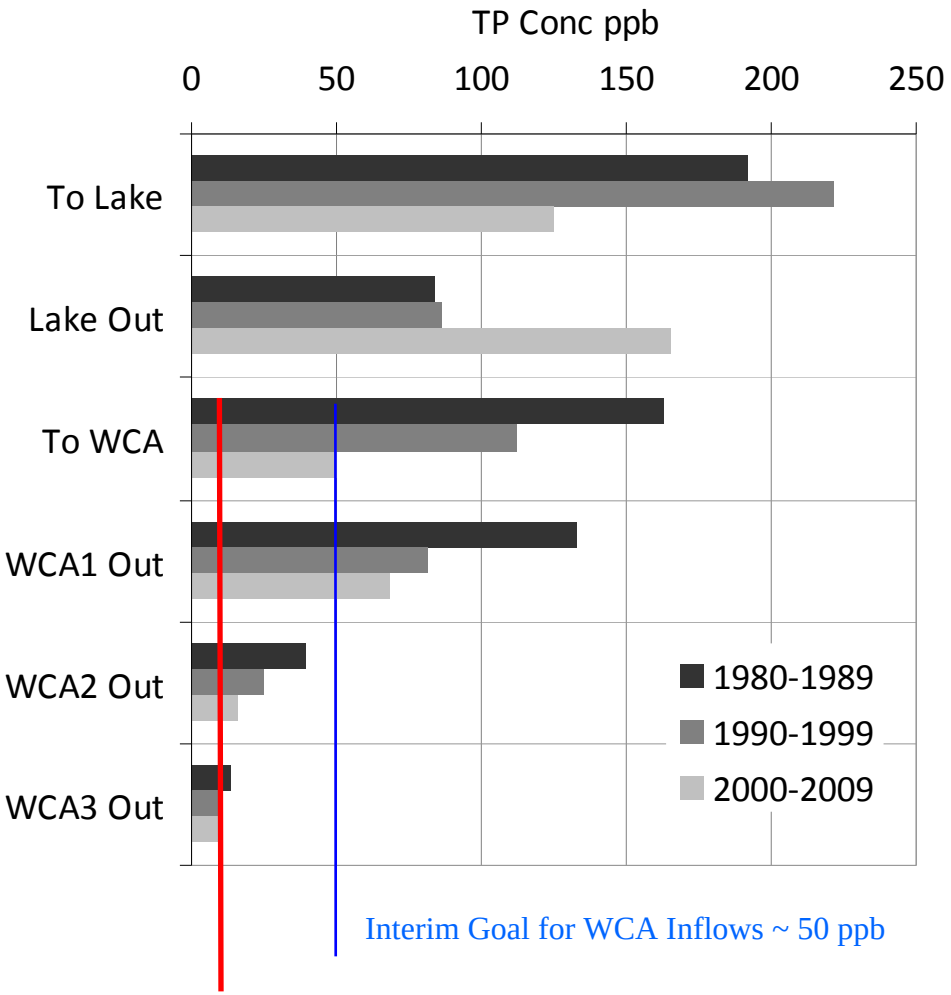
Long-Term Trends in Structure TP Concentrations
Flow-Weighted-Means, 1980-2009





Long-Term Trends in Structure TP Concentrations
Flow-Weighted-Means, 1980-2009



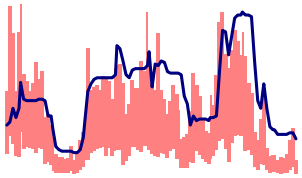


Tracking Responses to Everglades Phosphorus Controls, 2000-2009

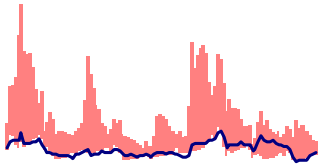
Data Shown vs. Target Zones (10th to 90th Percentiles) for Achievement of Management Goals

Target Zones Vary with Hydrologic Conditions (Rainfall, Flow, Water Level)

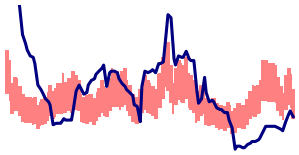
C139 Basin Farm Runoff Loads
Goal: No Change

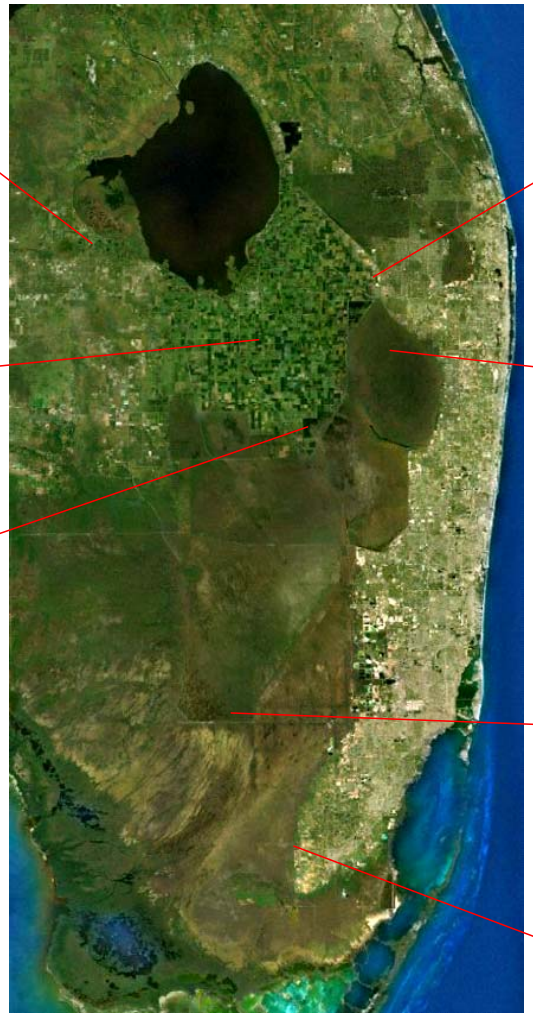


EAA Basin Farm Runoff Loads
Goal: 25% Reduction vs 1979-1988

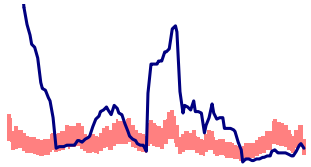


WCA Inflow P Load
Goal: 80% Reduction

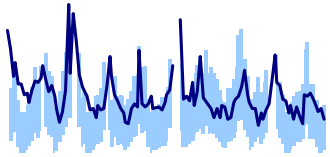




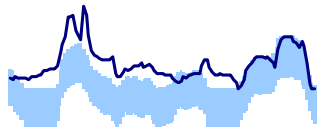
Loxahatchee Refuge P Load
Goal: 85% Reduction



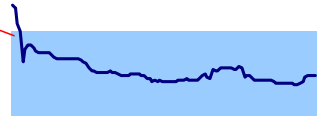
Lox Refuge Marsh P Conc
Goal: 1978-1979 Conditions



ENP Shark Slough Inflow P
Goal: 1978-1979 Conditions



ENP Taylor Slough Inflow TP
Goal: 1983-1984 Conditions

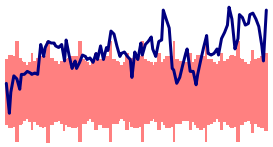


Tracking Responses to Everglades Phosphorus Controls, 2000-2009
Data Adjusted for Hydrologic Variations

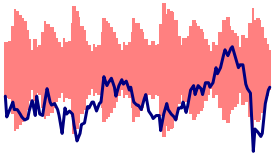
Data Shown vs. Target Zones (10th to 90th Percentiles) for Achievement of Management Goals

Target Zones Vary with Hydrologic Conditions (Rainfall, Flow, Water Level)

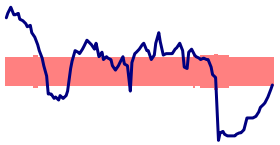
C139 Basin Farm Runoff Loads
Goal: No Change

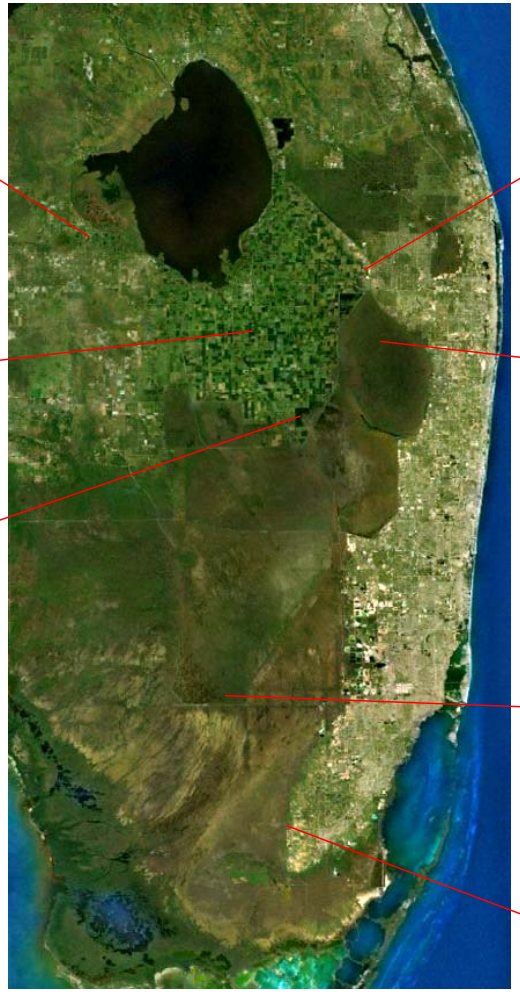


EAA Basin Farm Runoff Loads
Goal: 25% Reduction vs 1979-1988

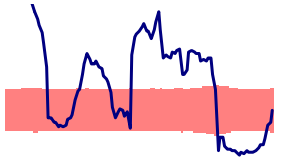


WCA Inflow P Load
Goal: 80% Reduction

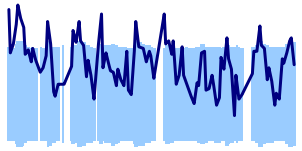




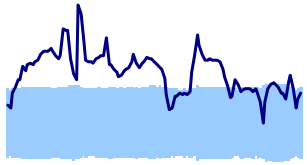
Loxahatchee Refuge P Load
Goal: 85% Reduction



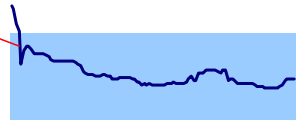
Lox Refuge Marsh P Conc
Goal: 1978-1979 Conditions



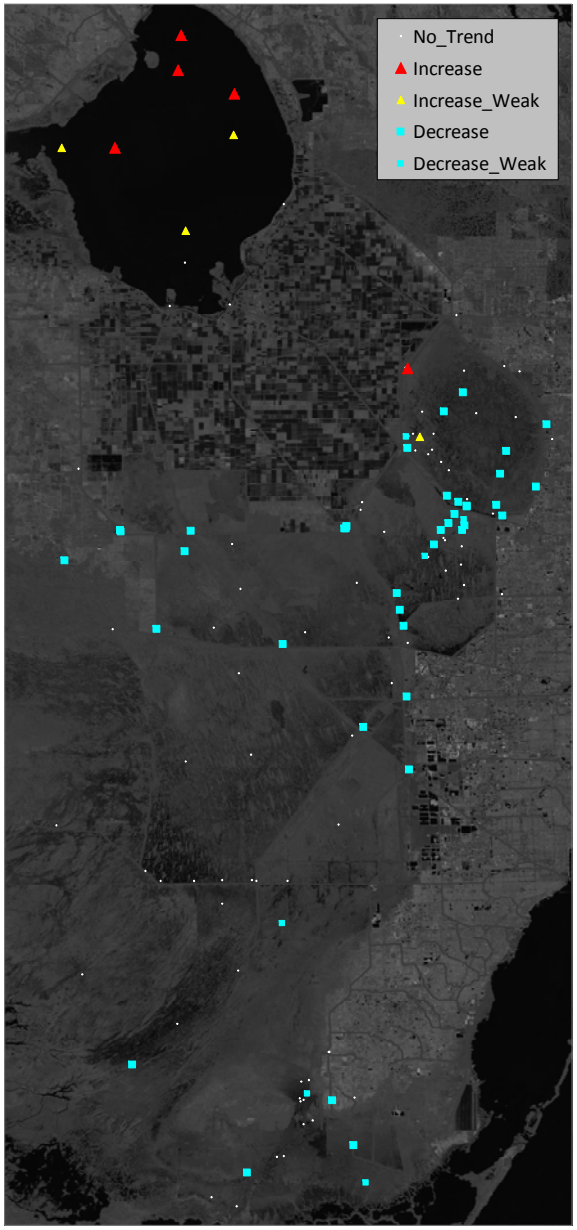
ENP Shark Slough Inflow P
Goal: 1978-1979 Conditions

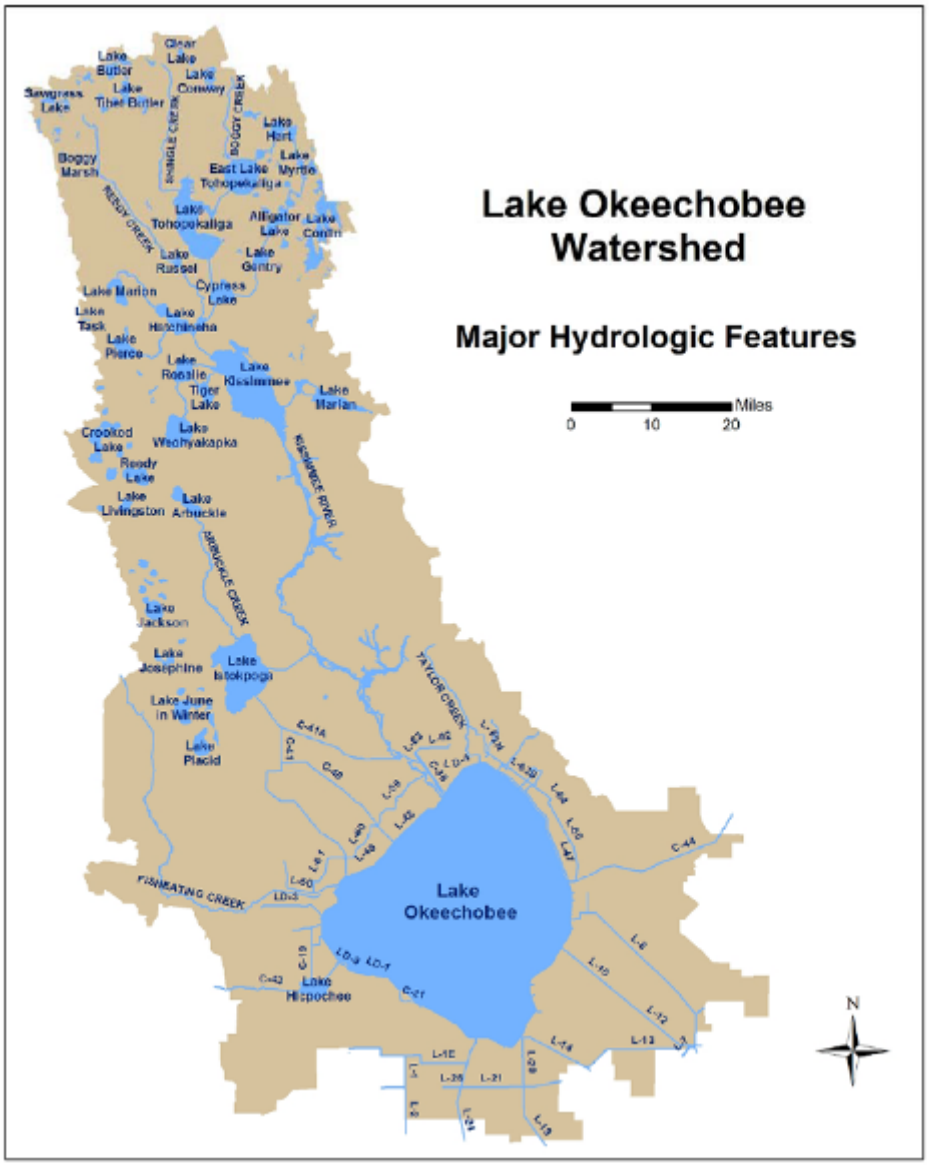


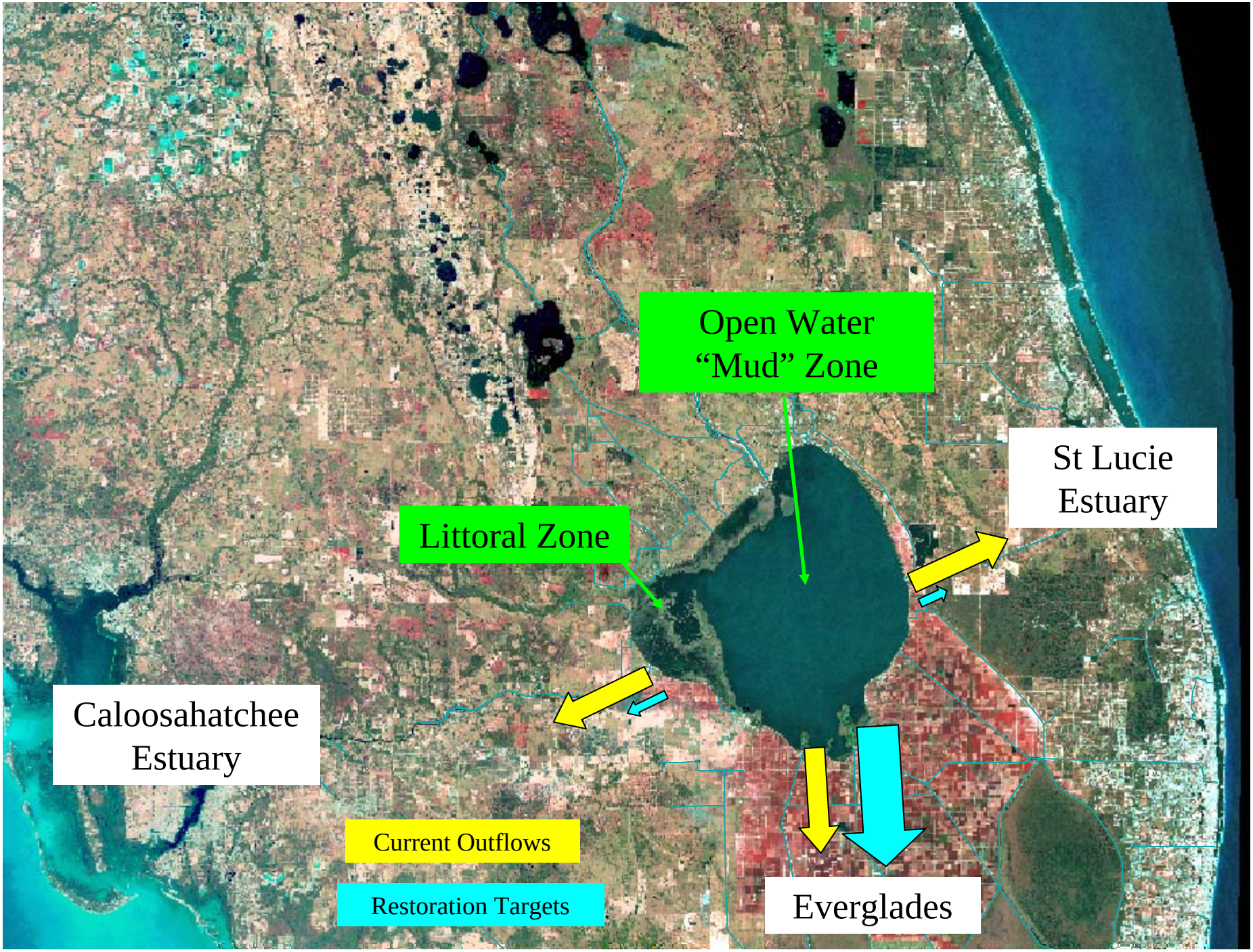
ENP Taylor Slough Inflow TP
Goal: 1983-1984 Conditions



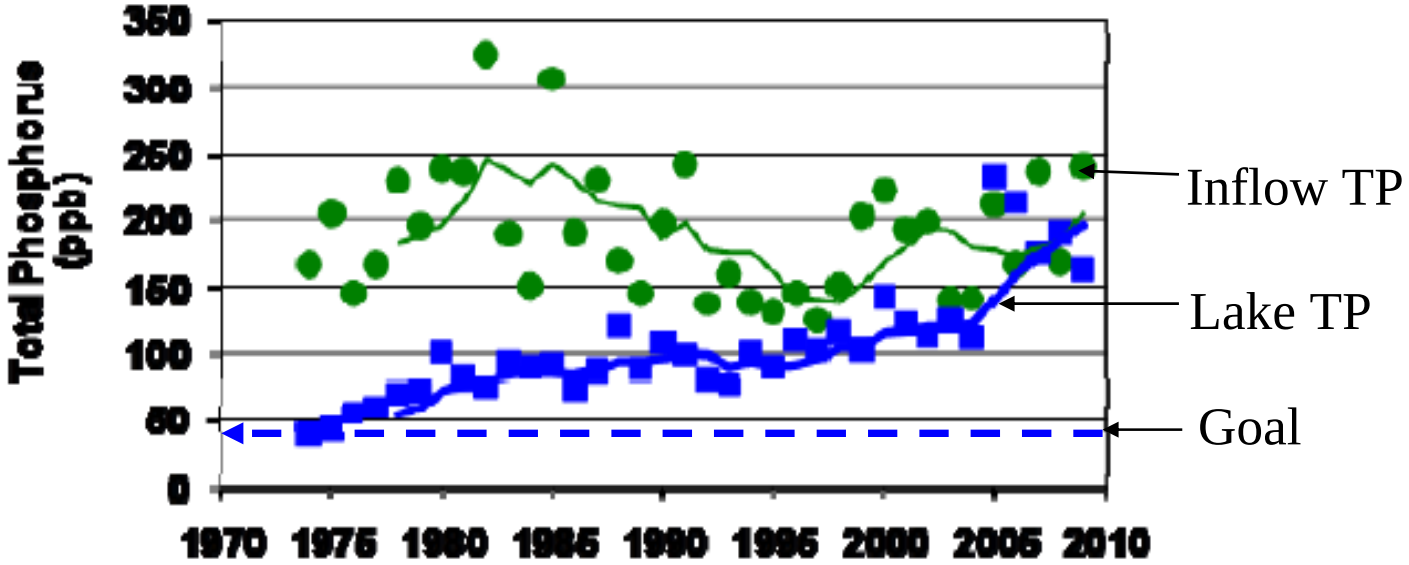
TP Concentrations & Trends at Long-Term Monitoring Sites, 2000-2009




Lake Okeechobee Watershed
Major Hydrologic Features
Miles
0
10
20
N
Lake Okeechobee
Lake Butler
Clear Lake
Lake Conway
Sawgrass Lake
Lake Tibet Butler
Lake Hart
Lake Myrtle
East Lake Tohopekaliga
Boggy Marsh
Lake Tohopekaliga
Alligator Lake
Lake Conlin
Lake Russel
Lake Gentry
Cypress Lake
Lake Marion
Lake Tack
Lake Hatchineha
Lake Pierce
Lake Rosalie
Lake Kissimmee
Tiger Lake
Lake Marian
Crooked Lake
Lake Weohyakapka
Reedy Lake
Lake Livingston
Lake Arbuckle
Lake Jackson
Lake Josephine
Lake Istokpoga
Lake June in Winter
Lake Placid
Lake Hicpochee
REEDY CREEK
SHINGLE CREEK
BOGGY CREEK
KISSIMMEE RIVER
ARBUCKLE CREEK
TAYLOR CREEK
FISHEATING CREEK


Open Water
“Mud” Zone
St Lucie
Estuary
Littoral Zone
Caloosahatchee
Estuary
Current Outflows
Restoration Targets
Everglades

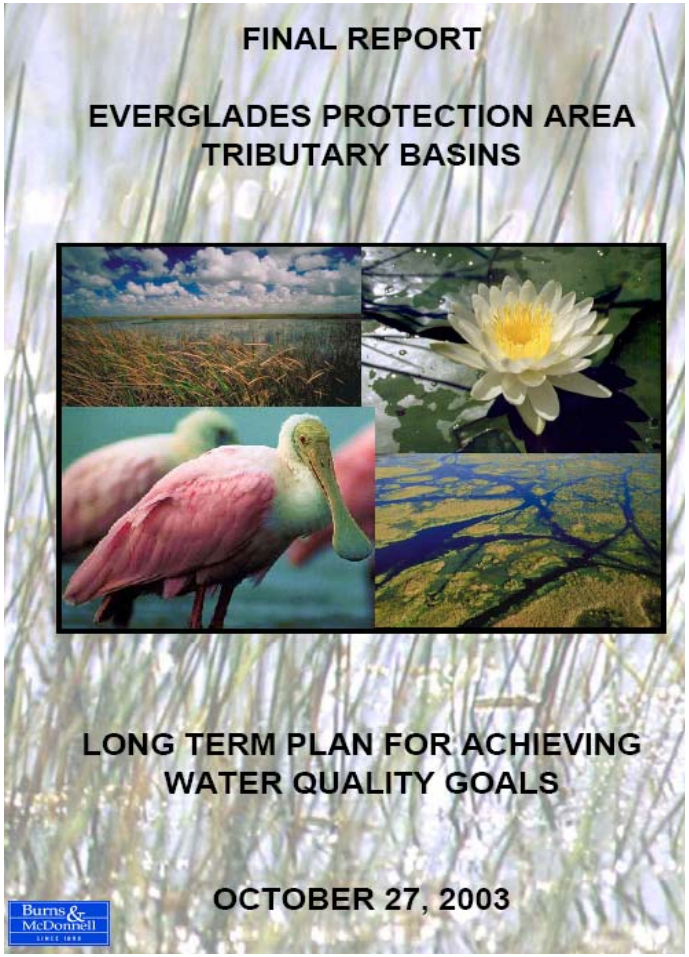
Long-Term Trends in TP Concentration



Factors Contributing to Increasing Lake P

- Excessive P Loads from Watershed
- Loss of P Assimilative Capacity
  - Sediment Enrichment
  - Decrease in Calcium Loads
  - Loss of Vegetation
  - High Water Levels & Fluctuations
  - Hurricanes - High Winds

State's Long-Term Plan for Achieving Compliance with Phosphorus Criterion



- Time Frame 2003 - 2016
- Adaptive Management Framework
- Integration with Hydrologic Restoration
- Monitoring / Research Components
- Modeling / Engineering Components
- Current Plans Not Projected to Meet Goals
- The Legal Dispute Continues...

Achieving Long-Term Water Quality Goals

- Integration with Hydrologic Restoration
  - Increases in Mean Flow
  - Changes in Seasonal & Annual Flow Variability
  - Reservoirs
- Additional Source Controls (BMPs)
- Additional Treatment Area
- Flow Equalization to Reduce Runoff Pulses
- Treatment Area Optimization
  - Internal Flow Distribution
  - Operation in Design Ranges
  - Vegetation Management
- Research, Monitoring, & Modeling

The End