Summary of the Science and Performance of the Everglades Stormwater Treatment Areas

June 27, 2005

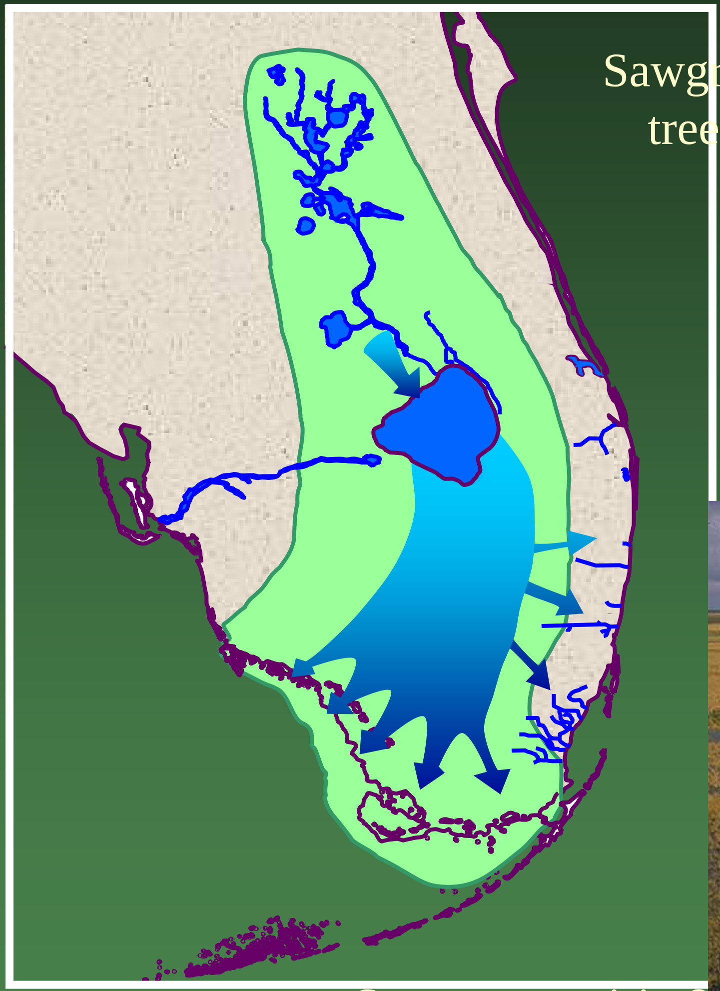
Gary Goforth, P.E., Ph.D.

Overview

- Background
- Stormwater Treatment Area Science
- Stormwater Treatment Area Performance
- Future Water Quality Strategies

The Historic Everglades Ecosystem

"River of Grass"

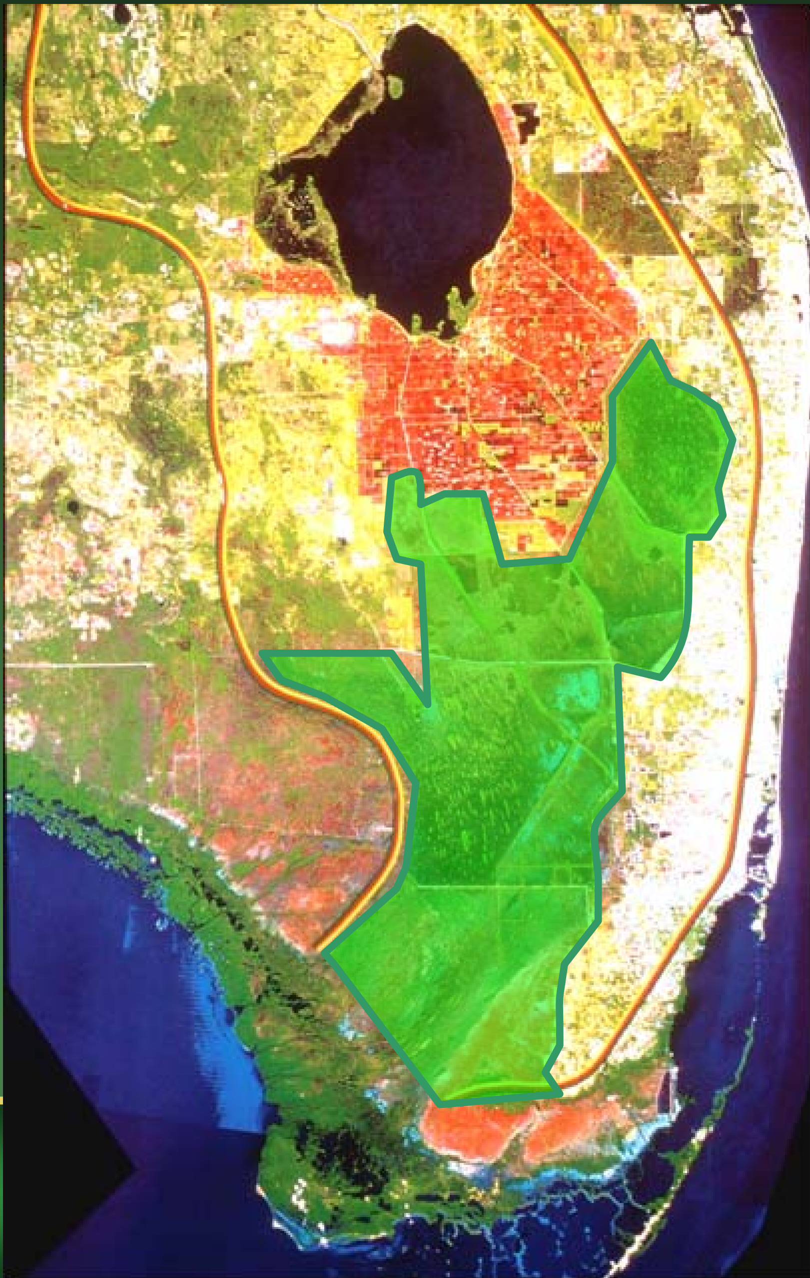


Sawgrass and
tree islands

Sawgrass prairie &
open water sloughs

Major Problems Facing Everglades

- **Loss of Everglades habitat**
- **Disruption of hydropatterns (i.e., timing, volume & distribution)**
  - **Repetitive water shortages and salt water intrusion**
  - **1.7 billion gallons of water a day wasted to tide**
- **Degradation of water quality**
- **Exotic plant species**



Brief Summary of Everglades Water Quality Initiatives

- WQ monitoring began in 1972 with expanded mission of SFWMD
- Initial studies linked to Lake Okeechobee
  - 1979: Diversion of EAA water south (IAP)
  - 1980s: water quality strategies including BMPs, on-site storage, advanced water treatment, use of wetlands for nutrient removal
- 1987: Surface Water Improvement Act
- 1988: Everglades Nutrient Removal project
  - 3,742-acre state-owned farm lease turned over to SFWMD for prototype of constructed wetland –
  - August 1994: flow-through operation began

Everglades Nutrient Removal Project

- Design target 50 ppb
- Model was unharvested cattail marsh in WCA 2A
- 2 flow paths compare performance of emergent vegetation with algae-dominated community
- Some planting; largely volunteer recruitment of vegetation
- Consistently reduced phosphorus to <25 ppb

Everglades Construction Project

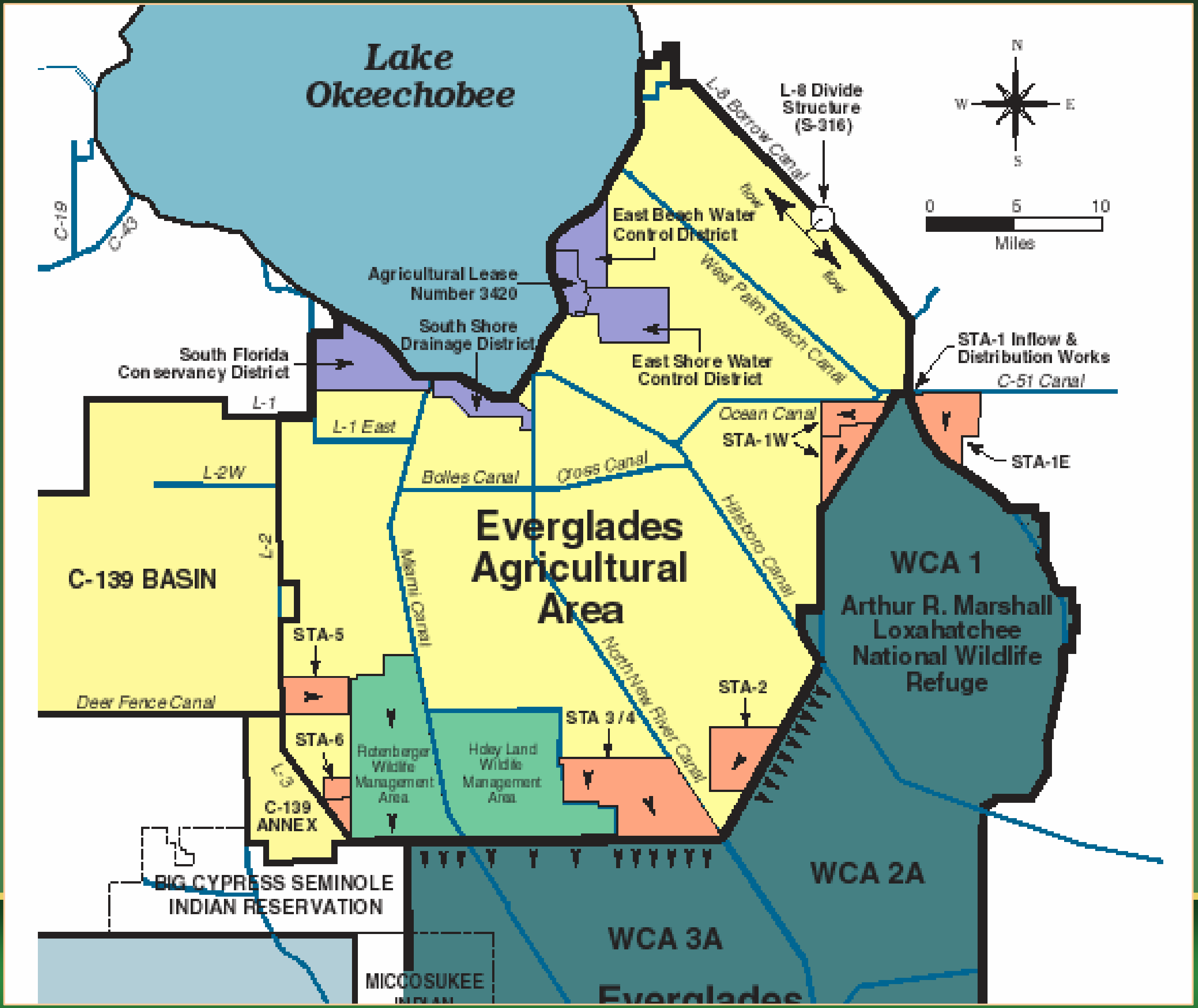
6 constructed wetlands

>40,000 acres

1.5 million AF/yr

$700 million

>167 tons/yr TP removal

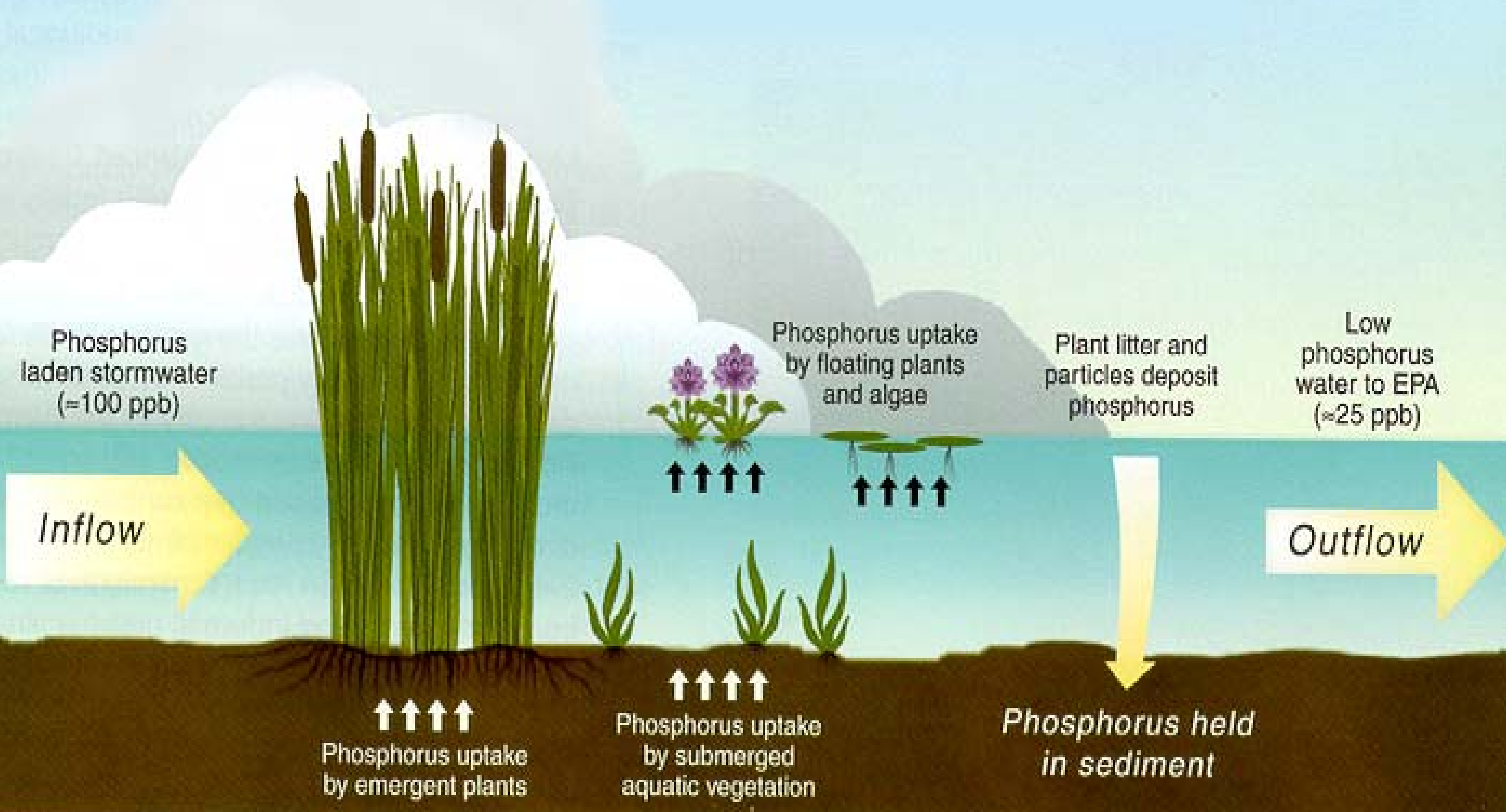


Everglades Construction Project - Objectives

- Reduce phosphorus levels, in conjunction with EAA BMPs, to an average of 50 ppb
- Increase supply of water into Everglades
- Improve distribution of inflows to Everglades
- Maintain flood protection for tributary basins; improve flood protection in C-51W basin
- Reduce discharges of freshwater to estuaries
- Reduce local phosphorus loading to Lake Okeechobee

Stormwater Treatment Areas

STAs are constructed wetlands that remove and store nutrients through plant growth and the accumulation of dead plant material in a layer of peat.



Summary of STA Science and Performance

Emergent Vegetation

Submerged Aquatic Vegetation

Periphyton-based Stormwater Treatment Area (PSTA)

June 27, 2005
Gary Goforth, Inc.

1st Generation Design Model

$$d(QC) / dA = p\, C_p - S$$

Where Q = flow

C = water column phosphorus concentration

A = effective treatment area

p = precipitation

Cp = atmospheric deposition of phosphorus

S = sediment accretion rate

Long-term phosphorus storage mechanism in the STAs

Simplifying Assumptions

- **Apparent background TP conc = atmospheric deposition TP conc**
- **Sediment accretion rate, assumed to be represented by first-order equation:**
  - **$S = K_e F_w C$**
  - **K_e = effective settling rate**
  - **F_w = wet period faction (%)**
- **Effective settling rate (K_e) is constant and independent of hydraulic and nutrient loading rates**
- **Area remains wet all year long (F_w = 100%)**
- **Plug flow, no hydraulic short circuiting**
- **Negligible interaction with groundwater**
- **Used 10-year average annual values**

Sizing of the STAs

$$A = \frac{Q\left\{\dfrac{(N\,C_i + K\,C_i - P\,C_p)}{(N\,C_o + K\,C_o - P\,C_p)}\right\}^{[\,1/(1 + K/N)]} - Q}{N}$$

Where: A = effective treatment area

Q = 10-yr average annual flow

Ci = 10-yr average annual inflow phosphorus concentration

Co = 10-yr average annual outflow phosphorus concentration (50 ppb)

K = effective settling rate (10.2 m/yr)

P = 10-yr average annual rainfall (1.233m/yr)

N = 10-yr average annual (rainfall - evapotranspiration) (0.083m/yr)

Cp = 10-yr ave annual atmospheric deposition of phosphorus (50 ppb)

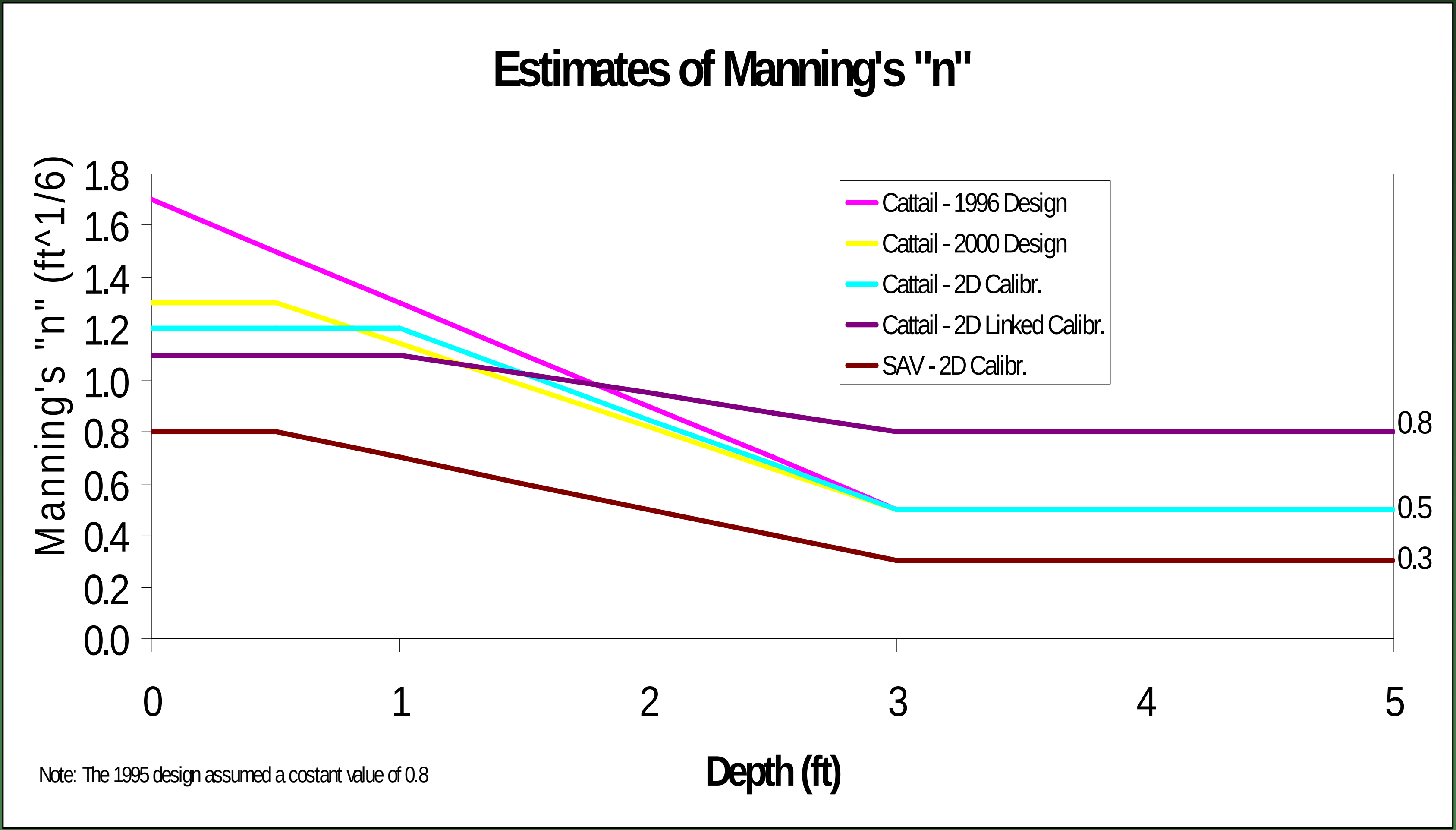
Summary of STA Sizes

STA	Flow AF/yr	Load MT/yr	Size acres	Removal MT/yr
STA 1E	125,000	29	5,350	23
STA 1W	143,000	38	6,670	31
STA 2	175,000	34	6,430	25
STA-3/4	600,000	87	16,480	53
STA 5	78,000	25	4,118	21
STA 6	54,000	13	2,280	10

Treatment Area Hydraulics

- Minimum depth of 6 inches to prevent dryout
  - Prevent oxidation and mobilization
  - Requires supplemental water
- Target depths designed to mimic depth exceedence relationship in WCA 2A
- Initial - average depth of 2 feet
  - Problems with large areas of floating cattails
  - Recently lowered to 1.25 and 1.5 ft
- Maximum depth of 4.5 feet
- Hydraulic residence times of 2-3 weeks

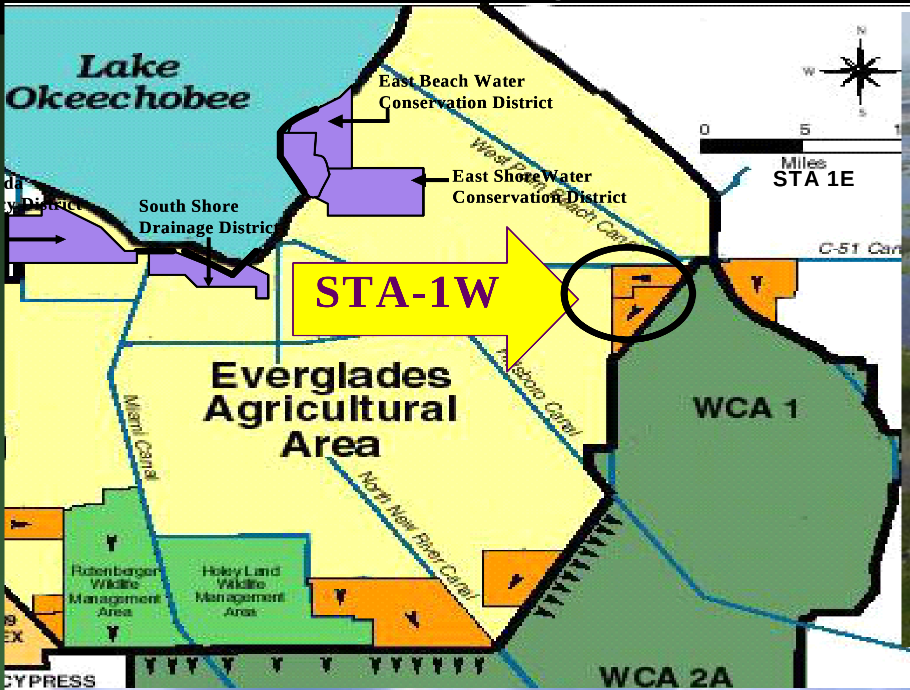
Vegetation resistance - Manning's "n" depth dependent; long flow paths (up to 5 miles) with dense vegetation



Early STA Models

- ENR performance estimate
- STA Sizing equation: 1st order steady state model
- Civil design – HEC-type models
- Flow distribution – FESWM/FLO2D
  - Tracer studies – rhodamine and lithium

Summary of STA Science and Performance

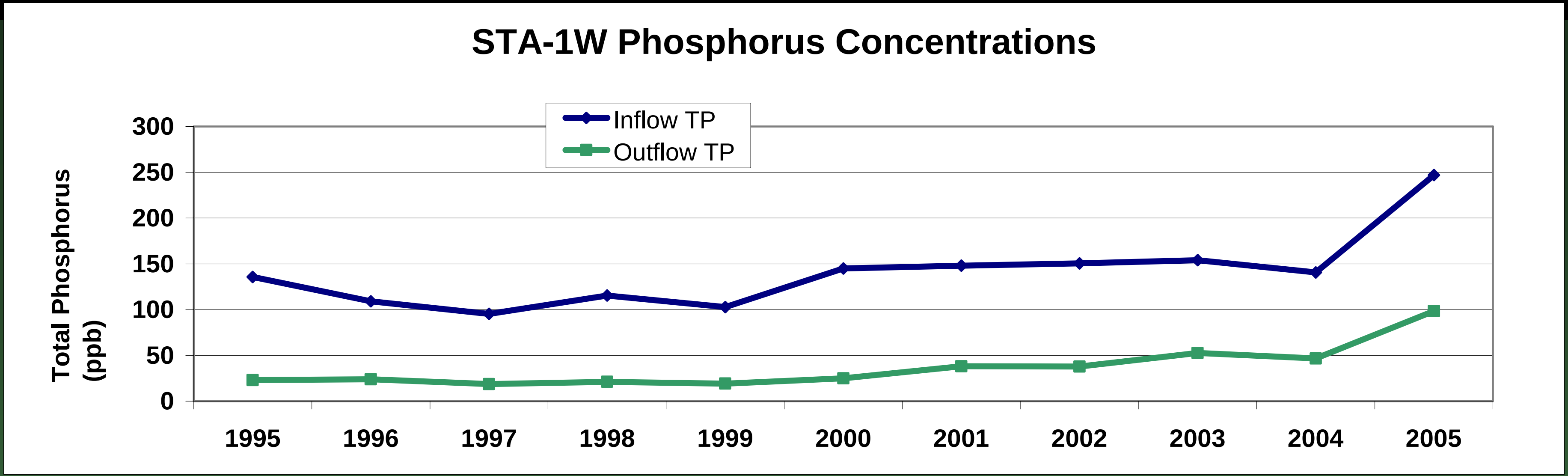


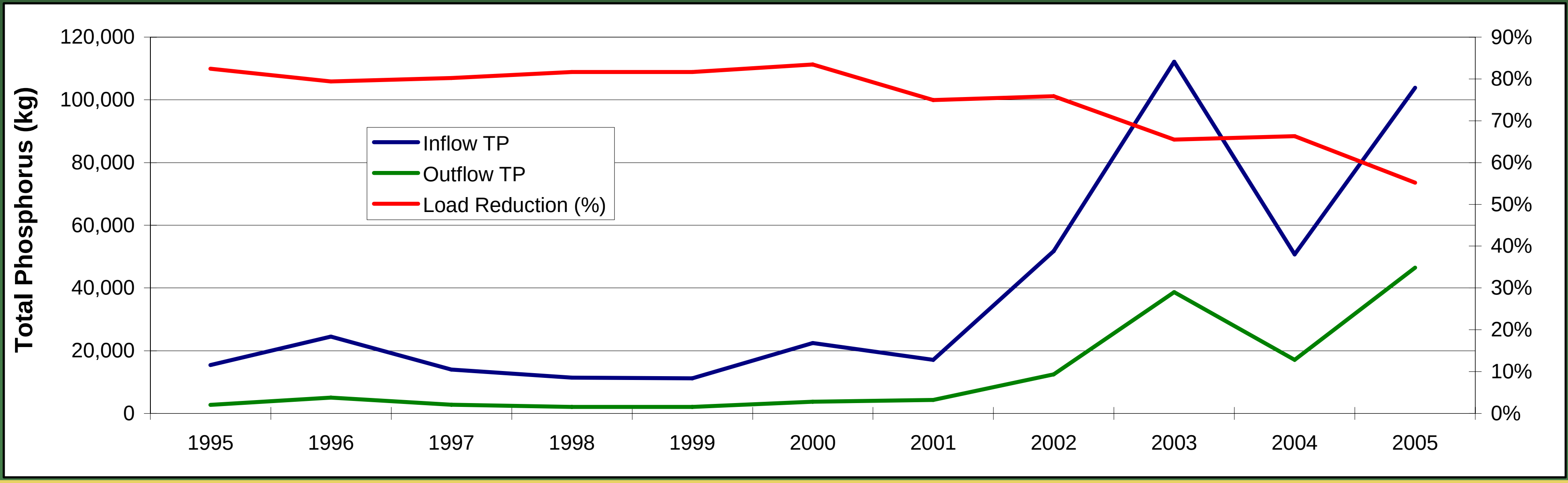
June 27, 2005
Gary Goforth, Inc.

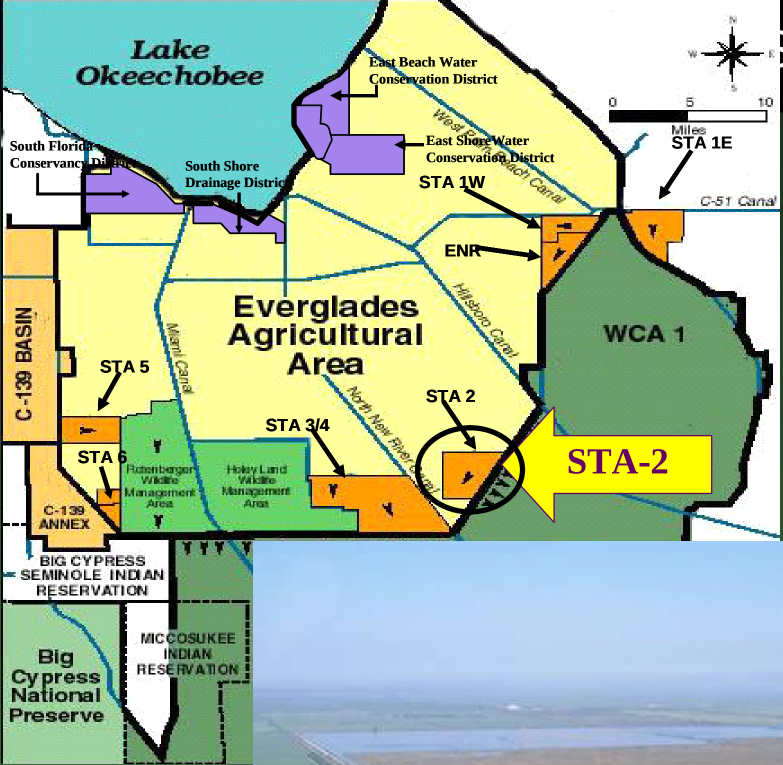
Summary of STA Science and Performance

Inflow structure for STA 1W

Summary of STA Science and Performance



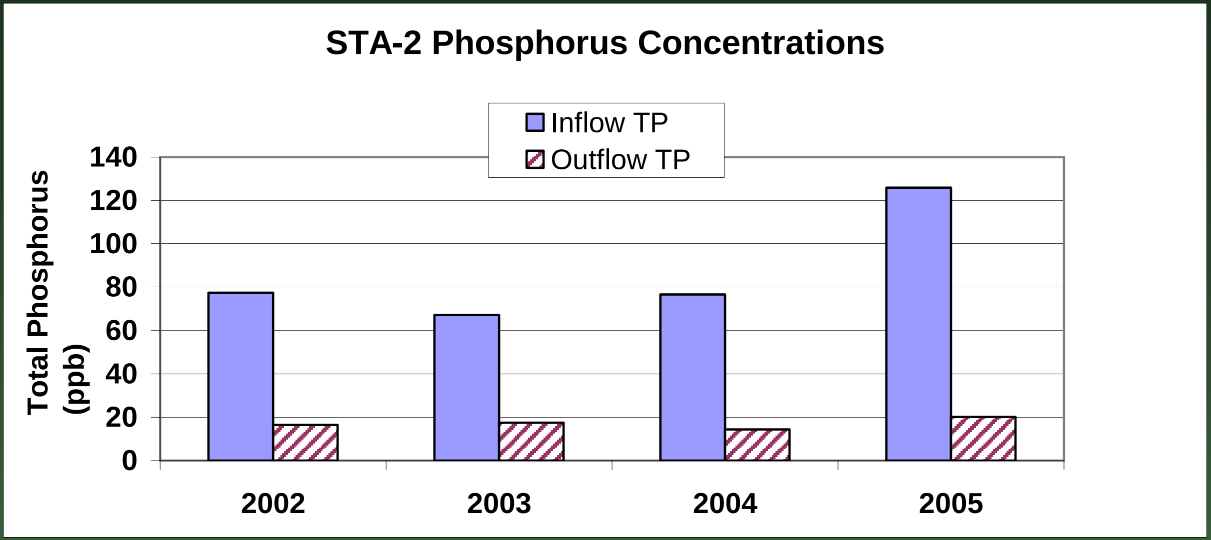


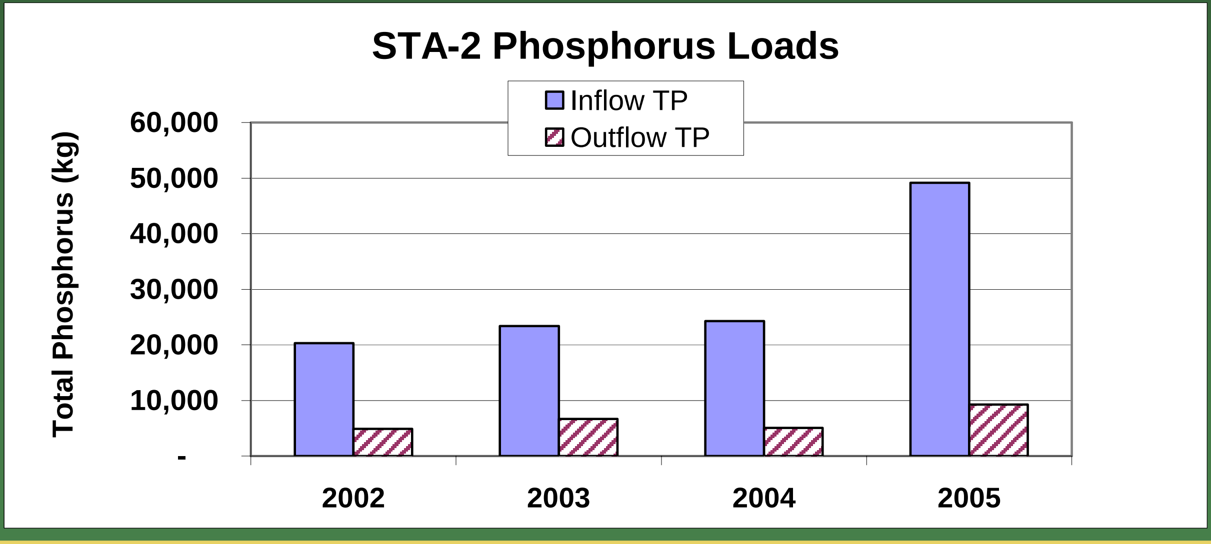


STA-2
6,430 acres
3 parallel flow-ways

STA-2 has a mixture of emergent & submerged vegetation

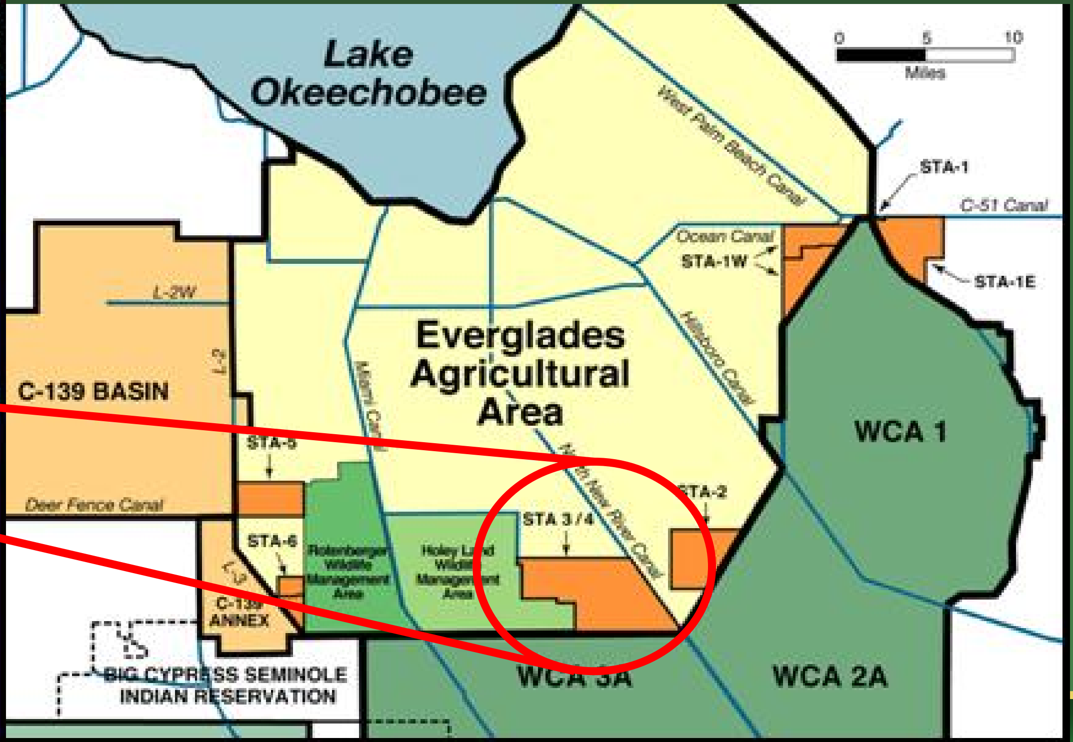
Summary of STA Science and Performance





Summary of STA Science and Performance

Stormwater Treatment Area 3/4 is the world's largest constructed wetland! Over 16,500 acres of former agricultural land has been converted to a biological treatment system designed to remove over 55 tons per year of phosphorus from water entering the Everglades.



June 27, 2005
Gary Goforth, Inc.

STA-3/4 – 3 parallel flow-ways with emergent vegetation followed by SAV

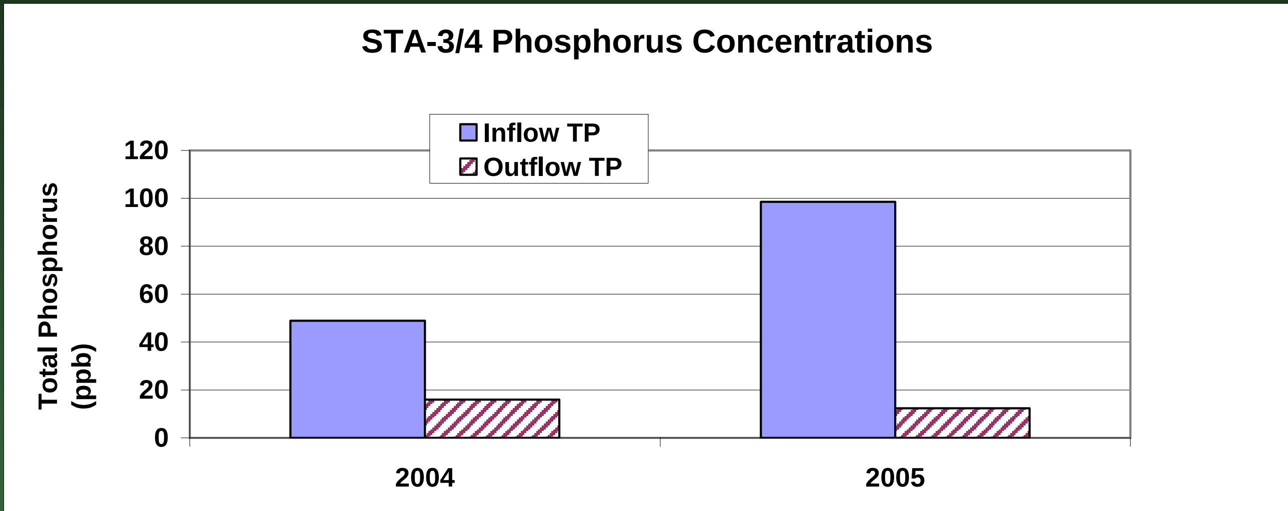
Summary of STA Science and Performance

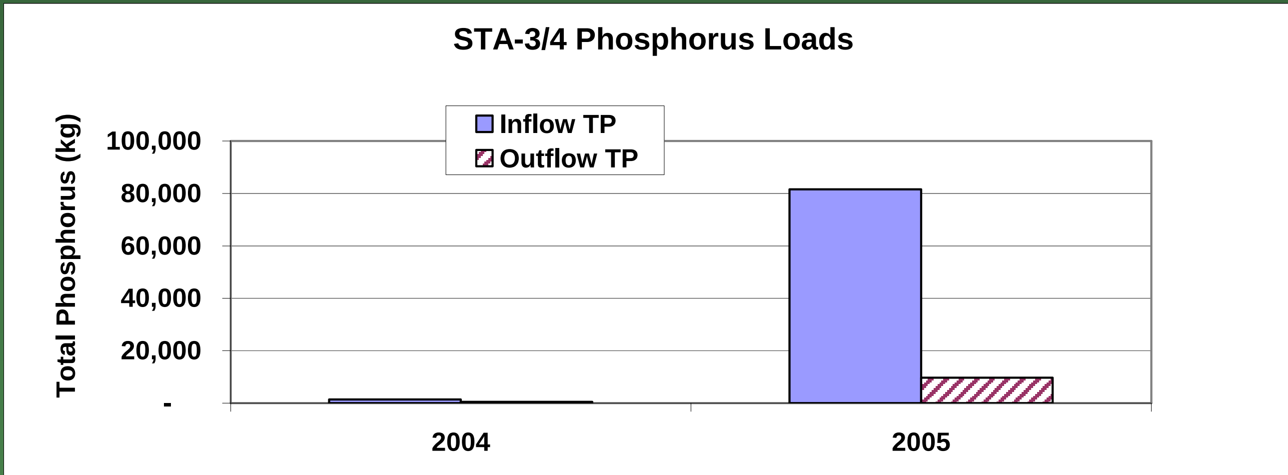
Performance during the initial 15 months has been incredible:

695,000 AF

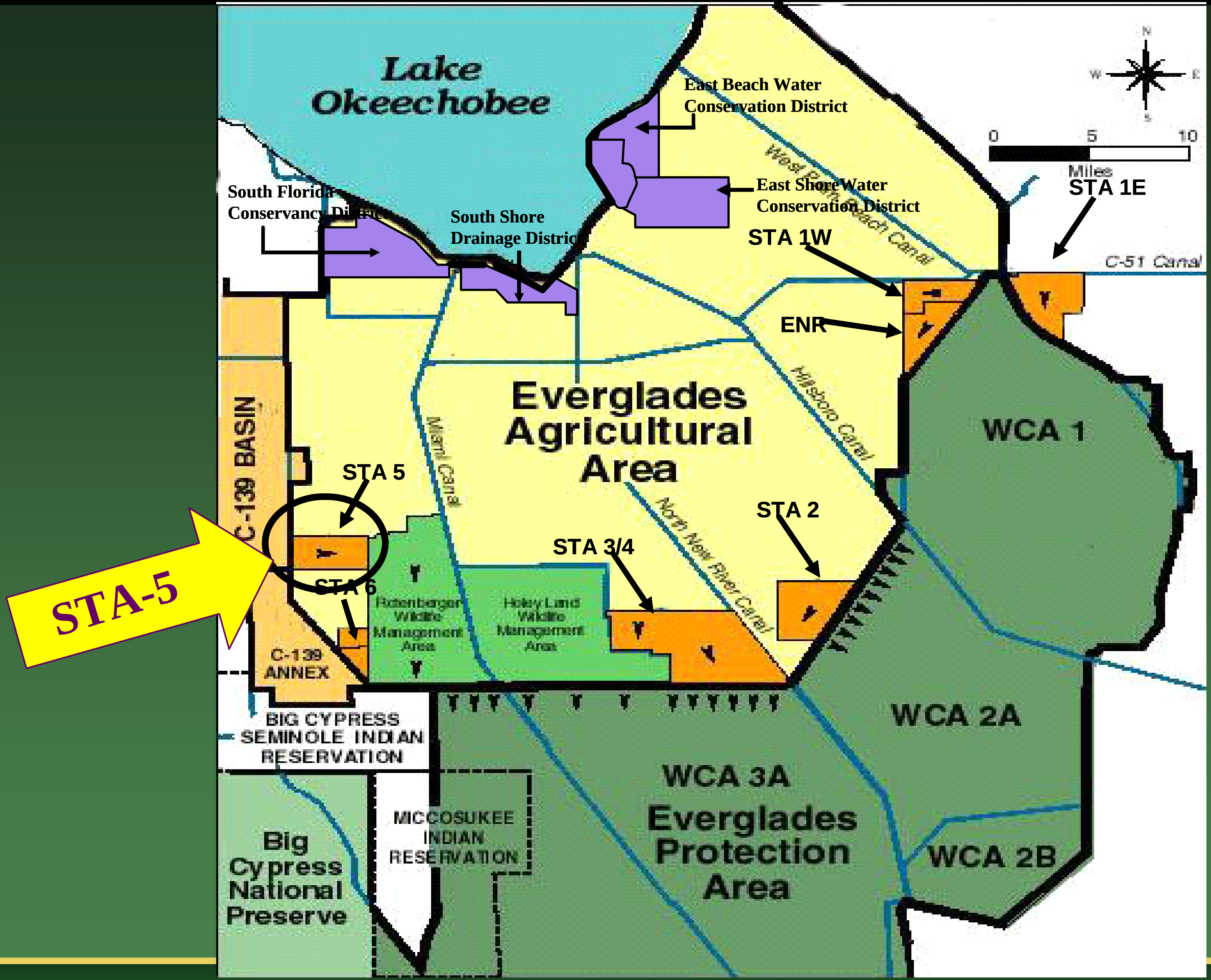
13 ppb

>72 tons removed!





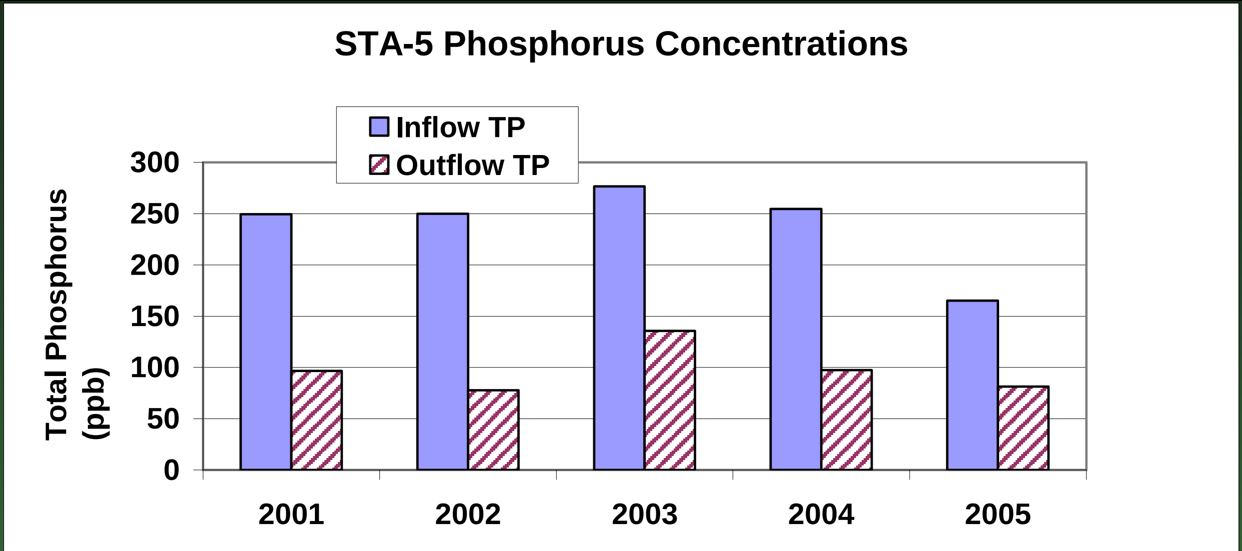
Summary of STA Science and Performance

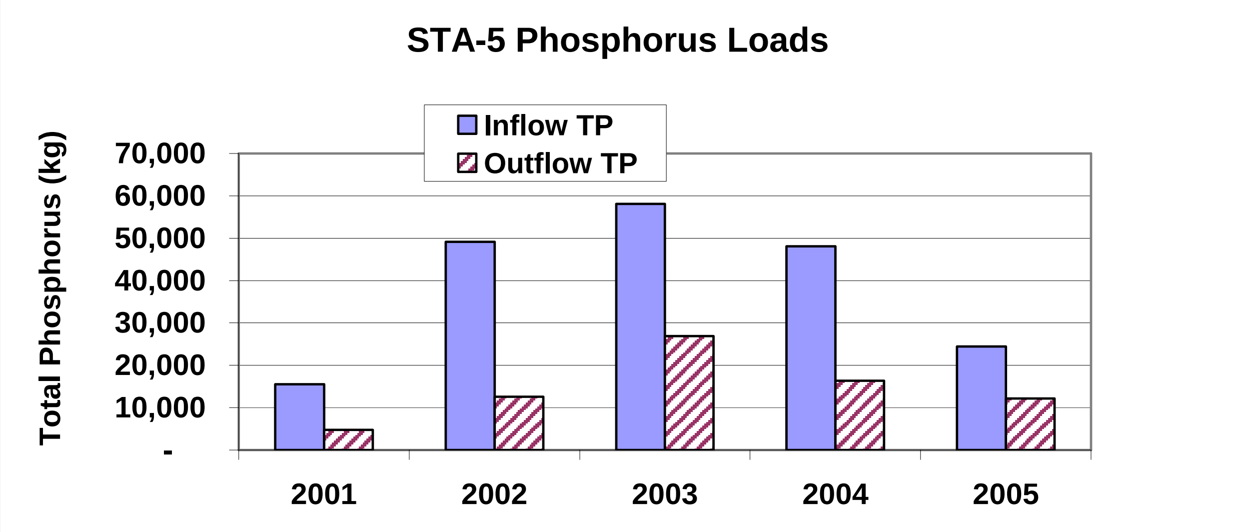


STA-5

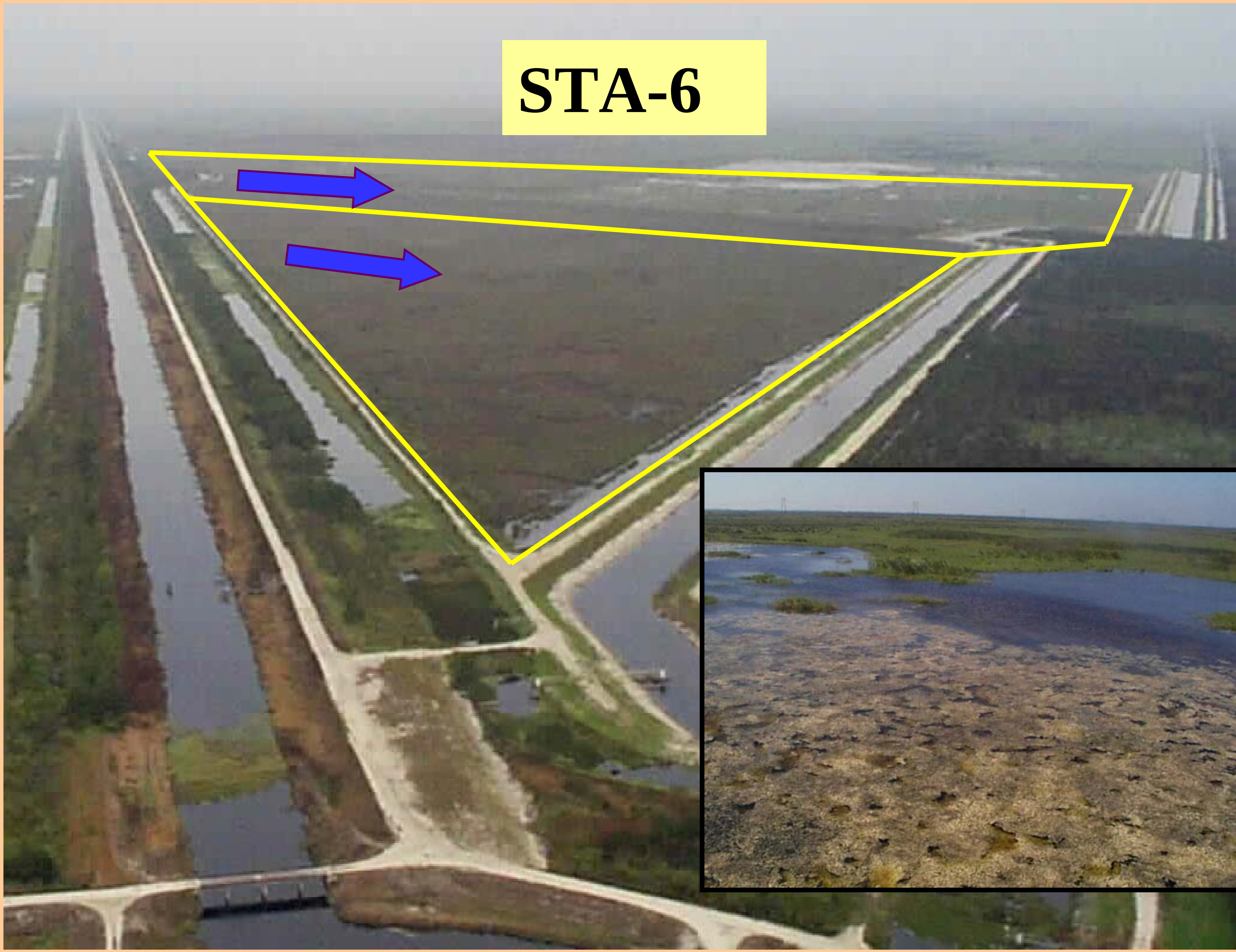
- 4,118 acres of effective treatment area
- Parallel flow-ways: emergent and the emergent followed by SAV

Summary of STA Science and Performance

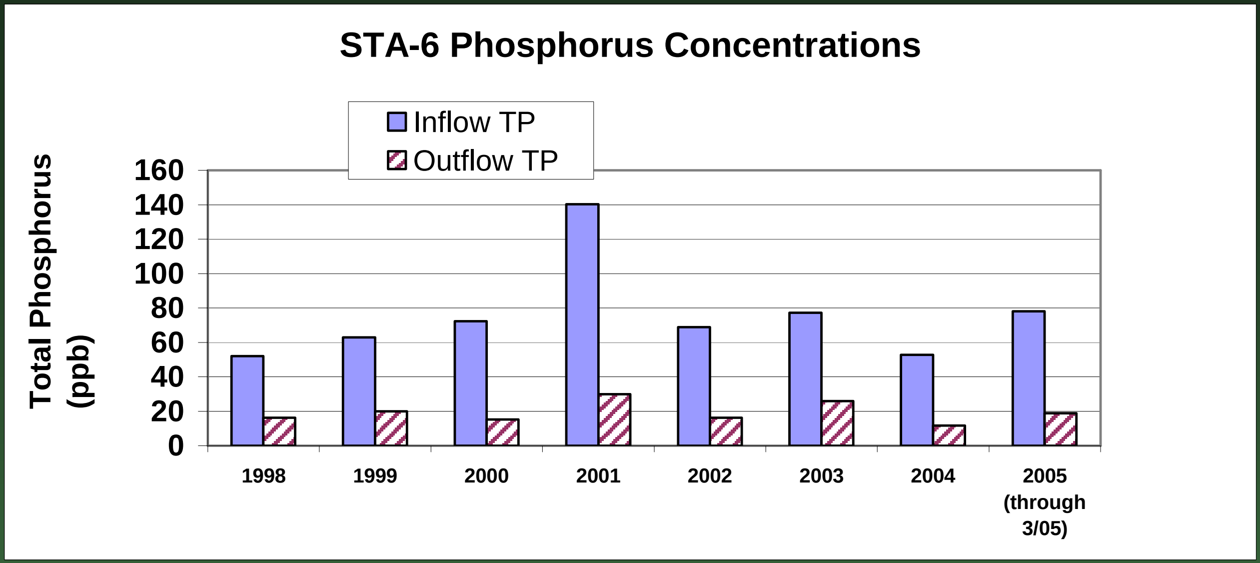


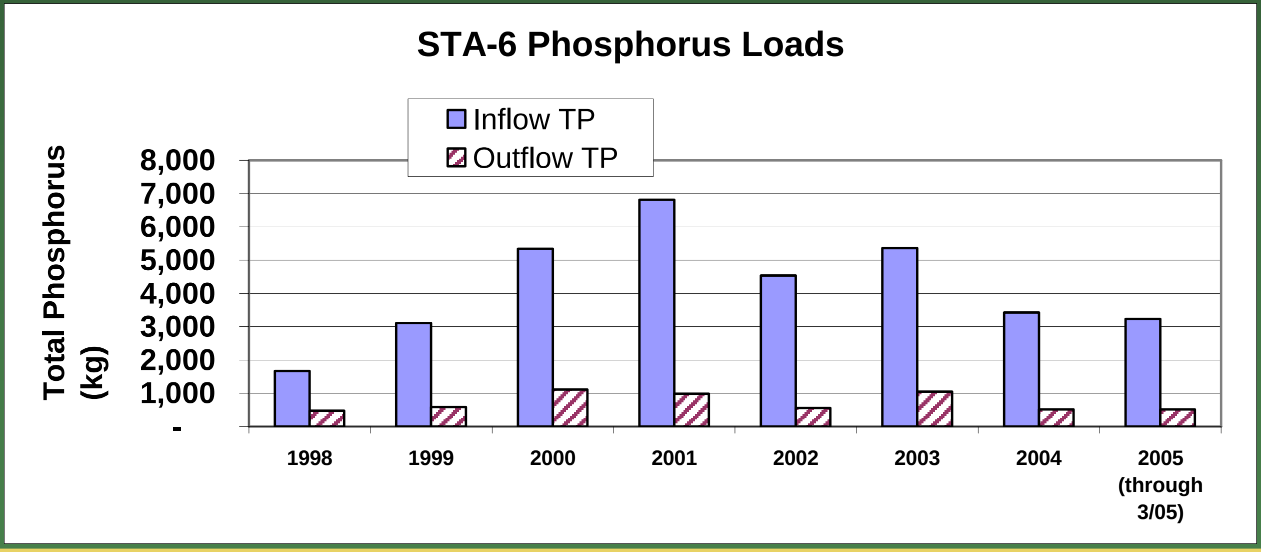


Summary of STA Science and Performance



Summary of STA Science and Performance

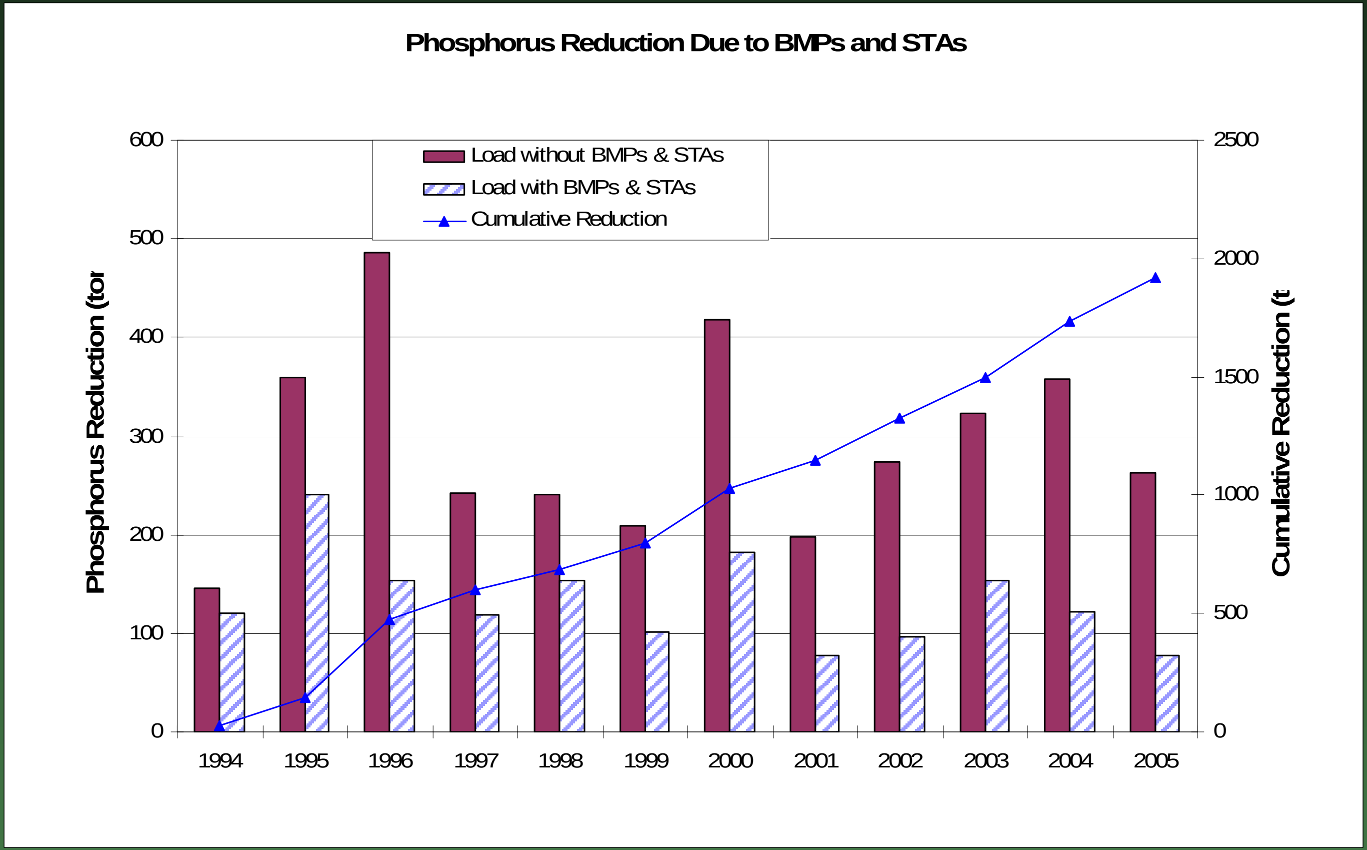




Summary of Performance (through May 2005)

- **In general, performance has exceeded expectation – outflow has averaged 41 ppb**
  - **STA-1W: 48 ppb – severely impacted by hurricanes**
  - **STA-2: 17 ppb**
  - **STA-3/4: 13 ppb**
  - *STA-5: 100 ppb*
  - **STA-6: 19 ppb**
- **611 metric tons removed; 71% removal**
- **Removal influenced by nutrient loading rate, inflow concentrations, soils, vegetation and hydraulic loading rate, depth**

Summary of STA Science and Performance



Despite success of EAA BMPs and STAs, need additional water quality improvement measures to achieve compliance with phosphorus standard by Dec. 31, 2006

STA Optimization Research

- Advanced treatment technologies
  - Narrowed down from dozens to less than 10
  - Supplemental Technology Standard of Comparison
- Results used by basin feasibility studies in evaluating alternative enhancements
- Continues today with full-scale monitoring and PSTA demonstration projects

Dynamic Model for Stormwater Treatment Areas (DMSTA – Walker and Kadlec, 2005)

Extensive calibration and verification with data from STAs, Everglades, and various research platforms

DMSTA2 Phosphorus Cycling Model

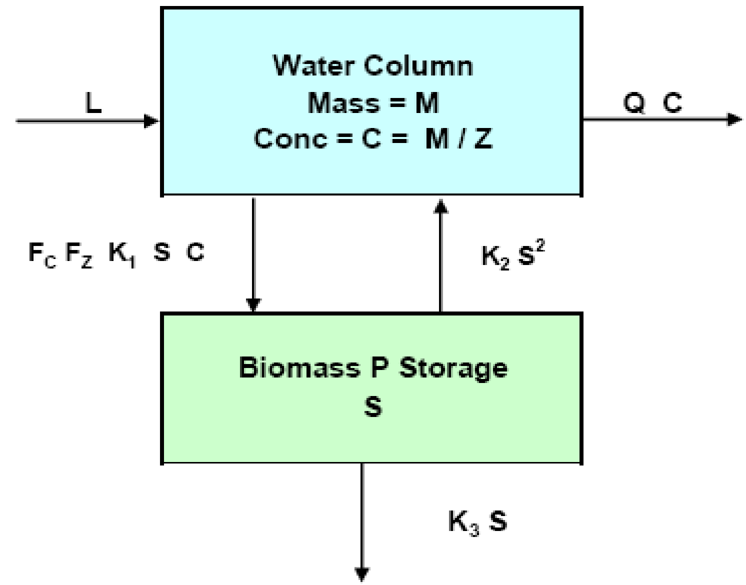
One CSTR at Steady-State

Unit Area Storage & Fluxes

Concs in mg/m3

Fluxes in mg/m2-yr

Storage in mg/m2



F_Z = Depth Multiplier

F_C = Conc Multiplier

State Variables:

M	Water Column P Storage	mg/m^2
S	Temporary P Storage in Biota, etc.	mg/m^2
Z	Water Column Mean Depth	m

Additional Ecological Monitoring

- Mercury
  - Atmospheric deposition is primary source
  - Soil chemistry and microbiology controls transformation to methyl mercury; sulfur plays a key role
  - Start-up and initial flooding are problematic – flow-through is key
- Other water quality parameters monitored
- Vegetation and biological also monitored
- Reference: *South Florida Environmental Report*

Additional Water Quality Solutions

- Expansion of BMPs (esp. urban basins)
- Expansion of STAs
- Enhancement of STAs
  - Vegetation conversion to SAV
  - Compartmentalization
  - Operations to balance flow and loads
  - Continue strong science-based program to optimize performance
- Synchronization with CERP projects
- *ADAPTIVE MANAGEMENT*
- *Collectively referred to as "Long-Term Plan"*

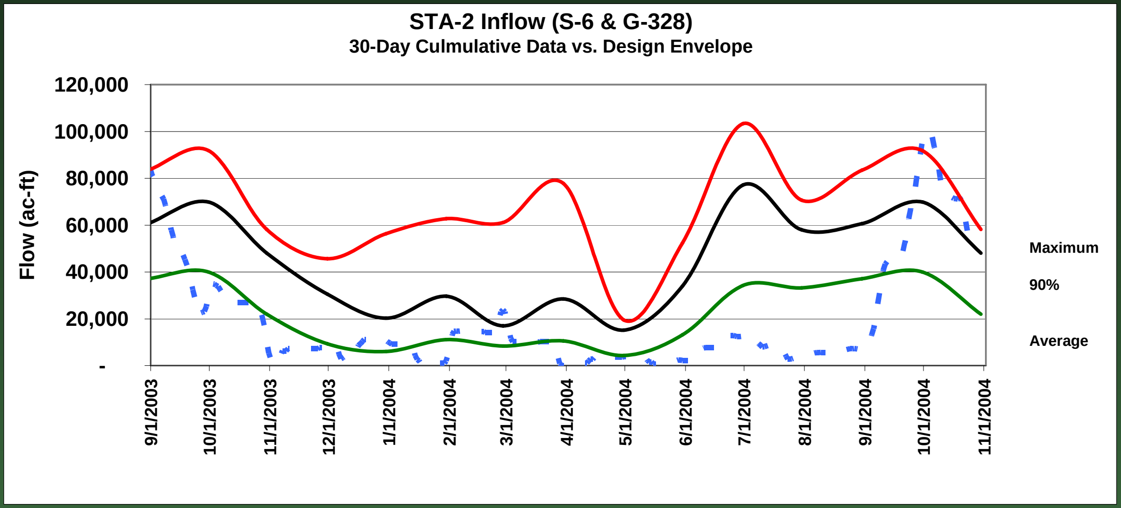
Summary of STA Science and Performance

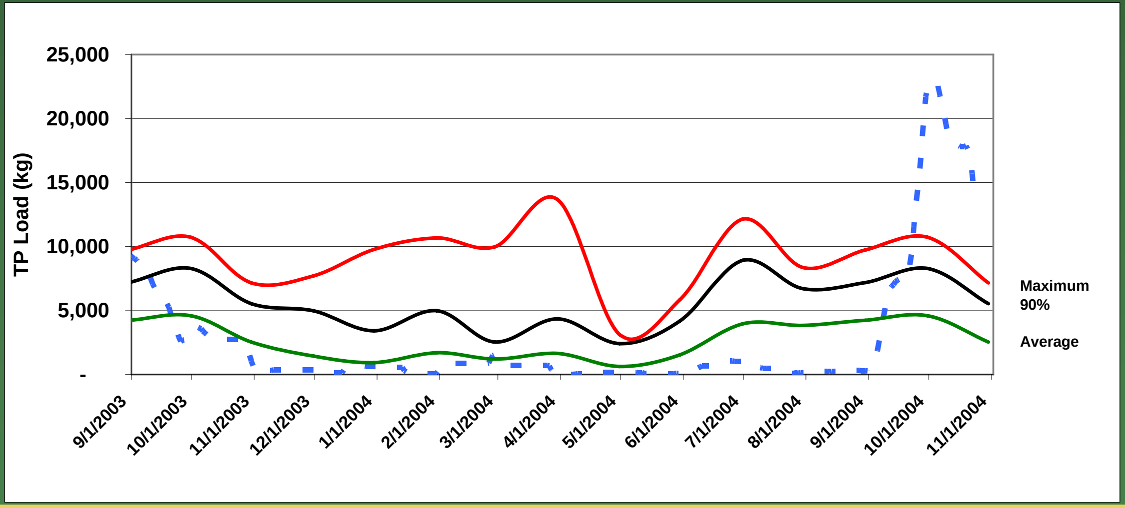
Refined operations of the STAs

Weekly assessment of actual loading vs. design envelope

Lowered target depths

Developing integrated operation plans





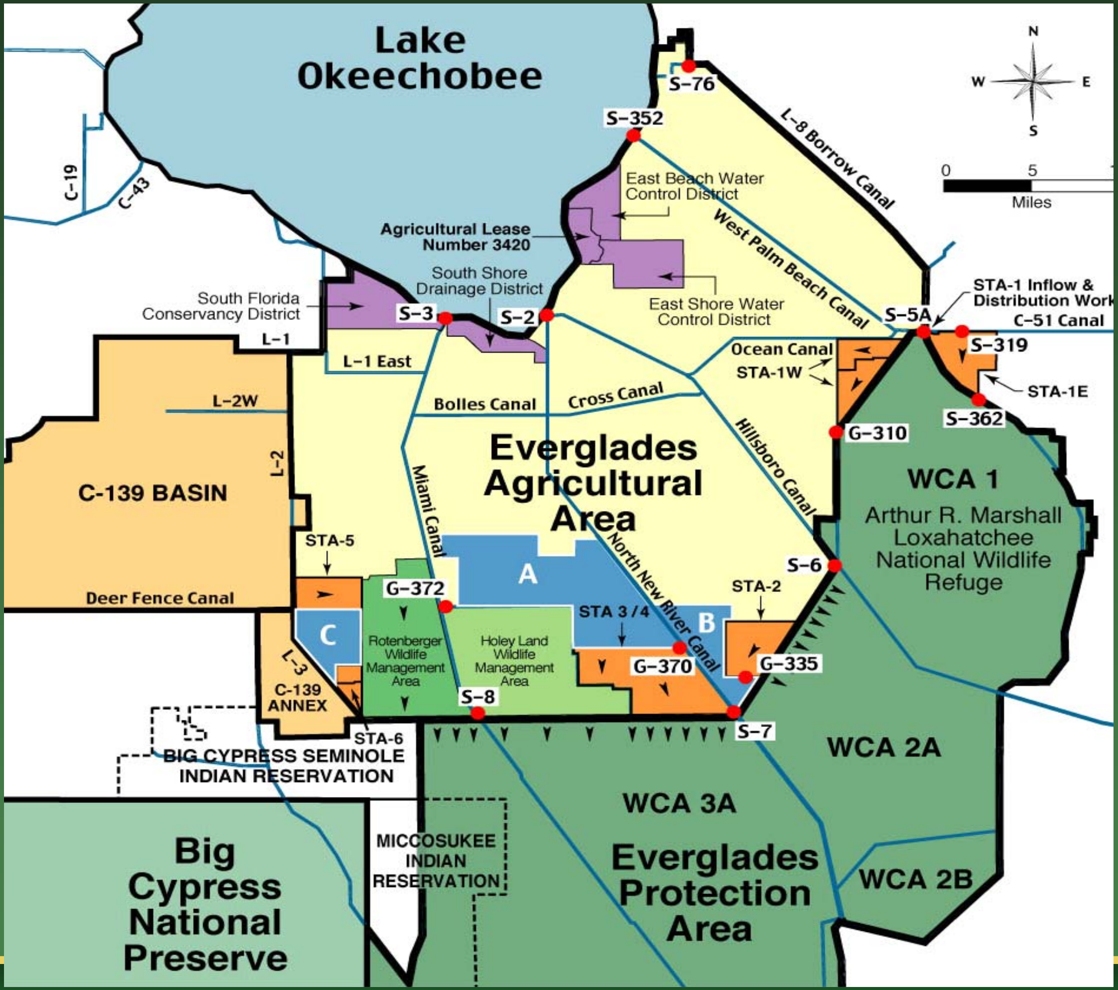
Summary of STA Science and Performance

STA-3/4 PSTA Demonstration Project

- Start-up underway
- Designed to receive full-scale flows and loads
- Modular design for replication in other cells

Expanded Treatment Areas

- **Storage requirements of EAA Reservoir can be met using just Compartment A**
- **Planning treatment areas on remaining 19,000 acres**



Future Plans

- Updating inflow data sets
- Use of 2nd generation design model (DMSTA) calibrated with full-scale STA performance
- Balancing loads among STAs
- Integrating with CERP projects

For More Information:

- www.sfwmd.gov
  - Everglades Restoration
  - Everglades Construction Project
  - Long-Term Plan (sfwmd.gov/org/erd/longtermplan/index.shtml)
- South Florida Environmental Report
  - Summary of all available data
  - http://www.sfwmd.gov/org/ema/everglades/index.html
- Gary Goforth
  - www.garygoforth.net

STA Science and Performance References

Chimney M. and G. Goforth (in press). History and Description of the Everglades Nutrient Removal Project.

Goforth G., K. Pietro, M. Chimney, J. Newman, T. Bechtel, G. Germain, and N. Iricanin, 2005, STA Performance, Compliance and Optimization, Chapter 4 in 2005 South Florida Environmental Report.

Abtew W., G Goforth, G. Germain, and T. Bechtel, 2004, Stormwater Treatment Areas: Constructed Wetlands for Phosphorus Removal in South Florida Surface Waters, Proceedings of the 2004 World Water and Environmental Resources Congress, June 27 – July 1, 2004.

Goforth, G., 2002, Foundation For Success: The Everglades Construction Project, in proceedings Watershed 2002.

Goforth G., 2000, Surmounting the Engineering Challenges of Everglades Restoration, In: Proceedings 7th International Conference on Wetland Systems for Water Pollution Control, University of Florida, Gainesville, Florida, pp. 697-705.

Chimney M. and Goforth G., 2000, Environmental Impacts to the Everglades Ecosystem: A Historical Perspective and Restoration Strategies. In: Proceedings 7th International Conference on Wetland Systems for Water Pollution Control, University of Florida, Gainesville, Florida, pp. 159-168.

Chimney M., Nungesser M., Newman J., Pietro K., Germain G., Lynch T., Goforth G., Moustafa Z., 2000, Stormwater Treatment Areas – Status of Research and Monitoring to Optimize Effectiveness of Nutrient Removal and Annual Report on Operational Compliance, Chapter 6 in 2000 Everglades Consolidated Report.

Walker, W.W., Jr., 1995. Design basis for Everglades stormwater treatment areas. Wat. Res. Bull. 31: 671-685.

Guardo, M., L. Fink, T.D. Fontaine, S. Newman, M. J. Chimney, R. Bearzotti, and G. Goforth, 1995, Large-Scale Constructed Wetlands for Nutrient Removal from Stormwater Runoff: An Everglades Restoration Project. Environmental Mgmt. Vol. 19, No. 6, pp. 879-889.

Burns & McDonnell. 1994. Everglades Protection Project Conceptual Design. February 1994. Report Prepared for the South Florida Water Management District, West Palm Beach, FL.

Goforth, G., J. B. Jackson, L. Fink, 1994, Restoring the Everglades, Civil Engineering.

Summary of Long-Term Plan References

Piccone T., and G. Goforth, 2005, Implementation of the Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area, Chapter 8 in South Florida Environmental Report.

SFWMD, Amendment to the Everglades Protection Area Tributary Basins Long-Term Plan for Achieving Water Quality Goals, Part 2: Revisions to Pre-2006 Strategies, ECP Basins, November 2004.

Piccone T., Goforth G., Van Horn S., Pescatore D., Germain G., 2004, Achieving Long-Term Water Quality Goals, Chapter 8A in 2004 Everglades Consolidated Report.

Burns & McDonnell. 2003. Everglades Protection Area Tributary Basins Long-Term Plan for Achieving Water Quality Goals. October 2003. Report Prepared for the South Florida Water Management District, West Palm Beach, FL.

Brown and Caldwell. 2002. Basin Specific Feasibility Studies for the Everglades Stormwater Program Basins. October 2002. Report Prepared for the South Florida Water Management District, West Palm Beach, FL.

Burns & McDonnell. 2002. Evaluation of Alternatives for the ECP Basins. October 2002. Report Prepared for the South Florida Water Management District, West Palm Beach, FL.

Walker, W.W. and R.H. Kadlec. 2002. Development of a Dynamic Model for Stormwater Treatment Areas. Report and Model Prepared for the U.S. Department of the Interior.

Goforth G., 2002, Achieving Long-Term Water Quality Goals, Chapter 8A in 2002 Everglades Consolidated Report.

Goforth, G. and T. Piccone. 2001. Baseline Data for the Basin-Specific Feasibility Studies to Achieve the Long-Term Water Quality Goals for the Everglades. South Florida Water Management District, West Palm Beach, FL.

Goforth G., 1999, Integrated Strategy to Achieve Water Quality Goals by 2006, Chapter 12 in Everglades Interim Report.

Hurricane Impacts – Sept. 2004

- Glancing blows from Hurricanes Frances, Ivan and Jeanne
- In general, STAs performed well
  - Inflow: 411,000 acre feet & 95 tons of phosphorus
    - 30% of annual flows; 60% of annual loads
  - 65 m tons removed (68%); average outflow = 54 ppb
  - STA-1W
  - Inflow: 70% of annual flows; 150% of annual loads
  - 20 m tons removed; average outflow = 127 ppb
  - Recovery Plan being implemented
    - Divert flows to other STAs
    - Restricted inflows to 5% of maximum – diversion to Refuge
    - Additional monitoring and assessment

Summary of STA Science and Performance