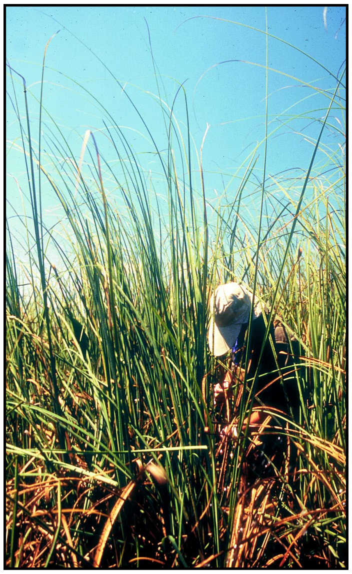
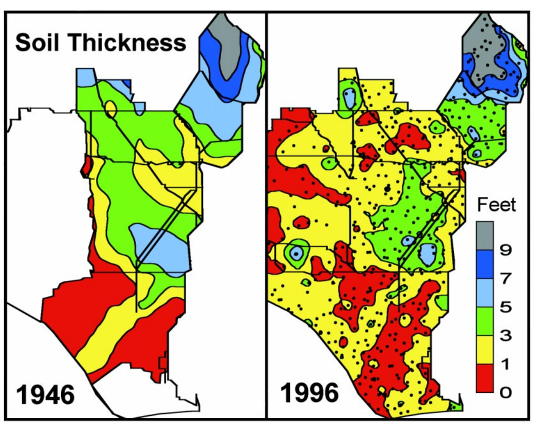
United States
Environmental Protection
Agency

Region 4 Science & Ecosystem
Support Division and Water
Management Division;
Office of Research and Development

EPA 904-R-00-003
September 2000

South Florida Ecosystem Assessment: Everglades Water Management, Soil Loss, Eutrophication and Habitat





Monitoring for Adaptive Management: Implications for Ecosystem Restoration

The South Florida Ecosystem Assessment Project is being conducted by the United States Environmental Protection Agency Region 4 in partnership with the Florida International University Southeast Environmental Research Center, FTN Associates Ltd., and Battelle Marine Sciences Laboratory. Additional cooperating agencies include the United States Fish and Wildlife Service, the National Park Service, the United States Geological Survey, the Florida Department of Environmental Protection, the South Florida Water Management District, and the Florida Fish and Wildlife Conservation Commission. The Miccosukee Tribe of Indians of Florida and the Seminole Tribe of Indians allowed sampling to take place on their federal reservations within the Everglades.

EPA 904-R-00-003
September 2000

SOUTH FLORIDA ECOSYSTEM ASSESSMENT

Everglades Water Management, Soil Loss, Eutrophication and Habitat

Daniel Scheidt
U.S. Environmental Protection Agency Region 4
Water Management Division
South Florida Office
West Palm Beach, Florida

Jerry Stober, Project Manager
U.S. Environmental Protection Agency Region 4
Science and Ecosystem Support Division
Athens, Georgia

Ronald Jones
Florida International University
Southeast Environmental Research Center
Miami, Florida

Kent Thornton
FTN Associates, Ltd.
Little Rock, Arkansas

This document is available on the Internet for browsing or download at:
<http://www.epa.gov/region4/sesd/sesdpub_completed.html>

EXECUTIVE SUMMARY

The United States Environmental Protection Agency South Florida Ecosystem Assessment Project is an innovative, long-term research, monitoring and assessment effort. Its goal is to provide timely scientific information that is critical for management decisions on the Everglades ecosystem and its restoration. The purpose of this report is to document 1993 to 1996 baseline conditions in the Everglades and Big Cypress prior to ecosystem restoration efforts. The project is unique to South Florida in two aspects: (1) its probability-based sampling approach permits quantitative statements about ecosystem health; and (2) its extensive spatial coverage and sampling intensity are unprecedented.

This project:

- contributes to the Comprehensive Everglades Restoration Plan by quantifying pre-restoration conditions in three physiographic regions: Everglades ridge and slough; marl prairie/rocky glades; and Big Cypress Swamp.

- provides information on four groups of Everglades restoration success indicators: water column, soils and sediments, vegetation, and fishes.

- provides a baseline against which future conditions can be compared and the effectiveness of restoration efforts can be gauged.

- assesses the effects and potential risks of multiple environmental stresses on the Everglades ecosystem such as water management, soil loss, water quality degradation, habitat loss, and mercury contamination.

- provides unbiased estimates of ecosystem health with known confidence limits, while allowing one to differentiate between seasonality and inter-annual variability versus the effects of restoration efforts.

- provides data with multiple applications: updating and calibrating surface water management models; updating models that predict periphyton or vegetation changes in response to phosphorus enrichment or phosphorus control; developing empirical models in order to better understand interrelationships among mercury, sulfur, phosphorus, and carbon; developing water quality standards to protect fish and wildlife.

Samples were collected from the freshwater portion of the Everglades and Big Cypress. From 1993 to 1996 surface water, soil or sediment, periphyton, and mosquitofish were sampled from about 200 canal locations and over 500 marsh locations. These samples represent the ecological condition in over 750 miles of canals and over 3,000 square miles of freshwater marsh. A second phase of sampling, conducted in 1999 at about 250 marsh locations, is summarized in companion reports.

Key findings:

- ***Pronounced water quality gradients:*** Water discharged from Everglades Agricultural Area canals is loading the public Everglades with excess phosphorus, carbon, and sulfur. Concentrations progressively decrease downstream.

- ***Canals are a conduit for pollutant transport:*** The canal system is an effective conduit for the transport of degraded water into and through the Everglades marsh system. Water management affects water quality. Downstream water quality would be improved if delivery canals were eliminated or if they were operated to maximize surface water sheetflow and the diluting influence of rainfall and cleaner marsh water.

- ***Varying water quality:*** Surface water conductivity, phosphorus, carbon, nitrogen, and sulfur vary greatly throughout Big Cypress and the Everglades and are dependent upon location, time of year, and water management practices.

- ***Phosphorus enrichment:*** As of 1995 to 1996, about 44% of the Everglades canal system and 4% of the marsh area had total phosphorus concentrations exceeding the 50 part per billion Phase I control target. As phosphorus control programs continue to advance, this probability-based sampling can be repeated to determine whether the Everglades' condition is improving.

- ***Soil loss in the public Everglades:*** From 1946 to 1996, about one-half of the peat soil was lost from about 200,000 acres of the public Everglades. Water management must be improved to maintain the remaining marsh soils if the plant communities and wildlife habitat of these wetlands are to be preserved.

- ***Marsh habitat a mosaic:*** Wet prairie and sawgrass marsh were the two dominant plant communities in the Everglades, representing 44% and 47% of the sites sampled. Water quantity and water quality must be managed to maintain these important habitats. Cattail was present at 10% of these sites, and was associated with elevated soil phosphorus or proximity to canals.

- ***Periphyton conspicuous:*** Well-defined periphyton mats, a defining characteristic of the Everglades marsh complex, were found at 67% of the sample sites.

- ***Ecological condition varies by location and time:*** The condition of the Everglades varied greatly with location. Rainfall-driven portions of the system that are distant from the influence of canal water, such as the interior of Arthur R. Marshall Loxahatchee National Wildlife Refuge and the southwest portion of Water Conservation Area 3A, were found to have good water quality and low soil phosphorus. The interior of Loxahatchee National Wildlife Refuge tended to have the most pristine water quality and the lowest phosphorus concentrations in peat soils. In contrast, northern Water Conservation Area 3A had poorer water quality, soil loss due to water management, elevated soil phosphorus, and cattail encroachment. Water Conservation Area 2A had evidence of phosphorus enrichment and cattail encroachment, along with high water sulfate and conductivity. Big Cypress had good water quality and no obvious indications of phosphorus enrichment. Water quantity conditions at a given location vary with season and year.

- ***Environmental threats interrelated:*** Ecological stressors such as water management, soil loss, water quality degradation, cattail expansion, and mercury contamination are often interrelated. Management actions must be holistic.

This project provides a critical benchmark for assessing ecosystem health and the effectiveness of Everglades restoration activities into the twenty-first century. As Everglades protection efforts proceed, this probability-based sampling can be repeated to document the effectiveness of these actions.

ABBREVIATIONS

cm = centimeter
cc = cubic centimeter
cfs = cubic feet per second
g = grams
hr = hour
ppb = parts per billion (ug/L)
ppm = parts per million (mg/L) or (mg/kg)
mg/kg = milligrams per kilogram (ppm)
mg/L = milligrams per liter (ppm)
ug/cc = micrograms per cubic centimeter
uMol/hr = micromoles per hour

AA = Alligator Alley (Interstate 75)
APA = Alkaline Phosphatase Activity
APTMD = Air, Pesticides, and Toxics Management Division
BCNP = Big Cypress National Preserve
BMPs = Best Management Practices
CERP = Comprehensive Everglades Restoration Plan
EAA = Everglades Agricultural Area
ENP = Everglades National Park
EMAP = Environmental Monitoring and Assessment Program
EPA = Everglades Protection Area
FIU = Florida International University
LNWR = Arthur R. Marshall Loxahatchee National Wildlife Refuge
NERL - ERD = National Exposure Research Laboratory, Ecosystem Research Division. Athens, Georgia
NERL - AMD = National Exposure Research Laboratory, Atmospheric Modeling Division. Research Triangle Park, North Carolina
ORC = Office of Regional Counsel
SESD = Science and Ecosystem Support Division
SERC = Southeast Environmental Research Center
SFWMD = South Florida Water Management District
TT = Tamiami Trail
USEPA = United States Environmental Protection Agency
WCA = Everglades Water Conservation Area
WCA3N = Water Conservation Area 3A north of Alligator Alley
WCA3S = Water Conservation Areas 3A and 3B south of Alligator Alley

US EPA REGION 4 SOUTH FLORIDA ECOSYSTEM ASSESSMENT

ACKNOWLEDGEMENTS

PARTICIPANTS IN THE US EPA REGION 4 EVERGLADES ASSESSMENT PROJECT

US EPA Region 4
Program Offices

APTMD
L. Anderson-Carnahan
D. Dubose
L. Page

ORC
P. Mancusi-Ungaro

SESD
B. Berrang
P. Meyer
C. Halbrook
M. Parsons
D. Smith
W. McDaniel
M. Wasko
J. Scifres
M. Birch
P. Mann
T. Slagle
T. Stiber
J. Davee
D. Colquitt
D. Kamens
R. Howes
G. Collins
J. Bricker
B. Noakes

US EPA - Office of
Research and Development

EMAP
R. Linthurst
K. Summers
T. Olsen

NERL-RTP
R. Stevens
R. Bullock
J. Pinto

NERL-ATHENS
R. Araujo
C. Barber
N. Loux
L. Burns

FIU-SERC
R. Jaffe
J. Trexler
Y. Cai
A. Alli
N. Black
I. MacFarlane
W. Loftus
J. Thomas

University of Georgia
S. Rathbun

Florida Department of
Environmental Protection
T. Atkeson

South Florida Water
Management District
L. Fink

Contractors
J. Maudsley, Mantech
B. Lewis, Mantech
M. Weirich, Mantech
D. Stevens, Mantech
M. McDowell, Mantech
C. Laurin, FTN Associates, Ltd.
J. Benton, FTN Associates, Ltd.
R. Remington, FTN Associates, Ltd.
B. Frank, FTN Associates, Ltd.
S. Ponder, Integrated Laboratory Systems
K. Simmons, Integrated Laboratory Systems
S. Pilcher, Integrated Laboratory Systems
E. Crecelius, Battelle Marine Sciences
B. Lasorsa, Battelle Marine Sciences

Funding for this study was provided by the United States Environmental Protection Agency Region 4 South Florida Office, West Palm Beach; the Office of Water; the Office of Research and Development; and the United States Department of Interior.

INTRODUCTION AND PURPOSE

The United States Environmental Protection Agency (USEPA) South Florida Ecosystem Assessment Project is an innovative, long-term research, monitoring, and assessment effort. Its goal is to provide timely scientific information that is needed for management decisions on the Everglades ecosystem and its restoration. The purpose of this report is to document 1993 to 1996 baseline conditions in the Everglades and Big Cypress prior to ecosystem restoration efforts. This project is unique to South Florida in two aspects:

- its probability-based sampling approach permits quantitative statements about ecosystem condition; and

- its extensive spatial coverage is unprecedented.

The South Florida Ecosystem Assessment Project:

- contributes to the Comprehensive Everglades Restoration Plan by quantifying pre-restoration conditions in three physiographic regions: Everglades ridge and slough; marl prairie/rocky glades; and Big Cypress Swamp.

- provides information on four groups of Everglades restoration success indicators: water column, soil and sediment, vegetation, and fish.

Figure 1. Numerous environmental issues threaten the Everglades “River of Grass,” such as water management, soil loss, water quality degradation, and habitat alteration.

GOAL: Provide timely ecological information that contributes to environmental management decisions on the Everglades and its restoration.

- provides a baseline against which future conditions can be compared and the effectiveness of restoration efforts can be gauged.

- assesses the effects and potential risks of multiple environmental stresses on the Everglades ecosystem such as water management, soil loss, water quality degradation, habitat loss, and mercury contamination.

- provides unbiased estimates of ecosystem health with known levels of uncertainty, while allowing one to differentiate between seasonality and inter-annual variability versus the effects of restoration efforts.

- permits spatial analyses and identifies associations that provide insight into relationships among environmental stresses and observed ecological responses.

- provides data with multiple applications: updating and calibrating surface water management models; updating models that predict periphyton or vegetation changes in response to phosphorus enrichment or phosphorus control; developing empirical models in order to better understand interrelationships among mercury, sulfur, carbon, and phosphorus; developing water quality standards to protect fish and wildlife.

USEPA Region 4 and the Florida International University Southeast Environmental Research Center began this project in 1993 to monitor the condition of the South Florida ecosystem. This project has been carried out in cooperation with the: Miccosukee Tribe of Indians of Florida, Seminole Tribe of Indians, United States Fish and Wildlife Service, National Park Service, United States Geological Survey, Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, and South Florida Water Management District.

This report describes the ecological condition of the Everglades and Big Cypress as documented in the intensive 1993 to 1996 Phase I sampling effort. A more technical presentation of the Phase I sampling can be found in Stober et al., 1998. Companion reports summarize the 1999 Phase II project sampling, mercury contamination, and the comparative risk assessment. All reports and data for the study are available on the internet at <http://www.epa.gov/region4/sesd/sesdpub.html>.

FIGURE 2. The Everglades wet prairie - sawgrass marsh mosaic.

BACKGROUND

THE EVERGLADES

"Here are no lofty peaks seeking the sky, no mighty glaciers or rushing streams wearing away the uplifted land. Here is land, tranquil in its quiet beauty, serving not as a source of water but as a last receiver of it."

"The Everglades were not really set aside for any kind of geological wonders or scenic features. It's the first national park set aside simply for its wildlife and the plants and trees - for its biological diversity."

President Harry Truman, Everglades National Park dedication, 1947.

The Florida Everglades is one of the largest freshwater marshes in the world. The marsh is a unique mosaic of sawgrass, wet prairies, sloughs, and tree islands. Just over 100 years ago, this vast wilderness encompassed over 4,000 square miles, extending 100 miles from the shores of Lake Okeechobee south to Florida Bay. The intermingling of temperate and Caribbean flora created habitat for a variety of fauna, including Florida panthers, alligators, and hundreds of thousands of wading birds. The Everglades of the past were defined by several major characteristics:

How the water flowed. Water connected the system, from top to bottom. Surface water flowed so slowly down the flat and level landscape that rainfall during one season was still available during another. The enormous amount of water storage capacity and the slow flow made wetlands and coastal systems less vulnerable to South Florida's variable and often intense rainfall[(1)].

Vastness. The large ecosystem area provided a variety of wildlife habitats. Millions of acres of wetlands provided large feeding ranges and diverse habitat needs for wildlife. The vastness produced abundant aquatic life while facilitating recovery from hurricanes, fires, and other natural disturbances[(1)].

Diverse mosaic of landscapes. The Everglades was a complex system of plant and animal life dictated in part by water regime - minimum, average, and maximum water depths, along with the duration of surface water inundation. This resulted in expansive areas of sawgrass marshes, wet prairies, cypress swamps, mangrove swamps, and coastal lagoons and bays[(1)].

Natural water quality conditions. There were no external sources of pollutants to the ecosystem. There was no urban development or agriculture. Nutrients, ions, and metals all occurred at natural concentrations. Surface water flowed slowly across the landscape, providing ample opportunity for cleansing by extensive wetlands. The sawgrass marshes and wet prairies of the Everglades developed under extremely low phosphorus conditions.

The mosaic of habitats, their vastness and the variety of water patterns supported the long-term survival of wildlife under a range of seasonal and annual water conditions.

A Troubled River

One century ago, the greatest threat to wading bird populations was hunting (Figure 3). During the last century, however, the Everglades has become a troubled system. In response to periods of drought in the 1930s and 1940s, and severe flooding with loss of human life in the 1920s and 1940s, the Central and Southern Florida Flood Control Project (the Project) was created in 1948 by federal legislation. Project purposes include flood control, water level control, water conservation, prevention of salt water intrusion, and preservation of fish and wildlife. The Project is one of the world's most extensive public water management systems, consisting of

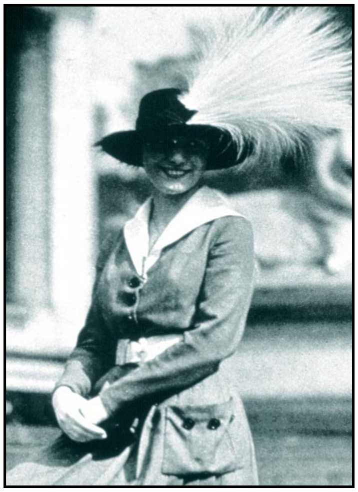


Figure 3. Decorating women's hats with wading bird plumage led to the near decimation of Everglades wading bird populations around 1900.

over 1,800 miles of levees and canals, 25 major pumping stations, and over 200 larger and 2,000 smaller water control gates or structures. When the Project was designed in the 1950s, about 500,000 people lived in the region and it was estimated that there might be two million people by 2000[1]. The Project has effectively provided flood control and water supply to facilitate urban and agricultural growth.

Today, 50% of the historic Everglades wetland has been drained. The Everglades ecosystem has been altered by extensive agricultural and urban development (Figures 4 to 8). South Florida's human population of about six million continues to increase and encroach on the ecosystem's land and compete for its water. This human population is projected to increase to 15 million within a few decades[1] (Figure 4).

The Everglades changed dramatically during the twentieth century as drainage canals were dug to facilitate urban and agricultural development. Most of the remaining Everglades are in the Everglades Protection Area (EPA): Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR), Everglades National Park (ENP), and the Water Conservation Areas (WCAs) (Figure 8). Everglades National Park, which was established in 1947, includes only one-fifth of the original "River of Grass" that once spread over more than 4,000 square miles (2 million acres)[3]. One-fourth of the historic Everglades is now in agricultural production within the 1,000 square mile Everglades Agricultural Area (EAA), where sugar cane and

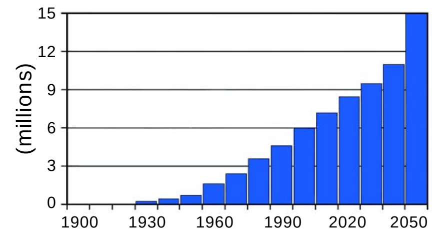


Figure 4. South Florida population from 1900-2050 (projected). Flood control provided by the Central and Southern Florida Project has made urban expansion possible[1, 2].

Figure 5. Urban expansion into drained Everglades wetlands within west Broward County, 1995. Note the black peat soil.

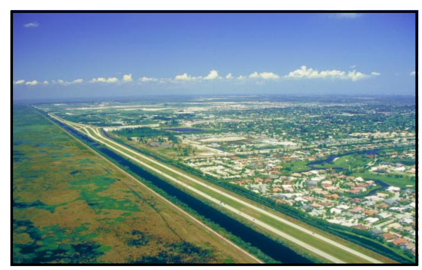


Figure 6. Urban expansion into Everglades wetlands in western Broward County, 1995.

Figure 7. Residential development on former Everglades wetlands.

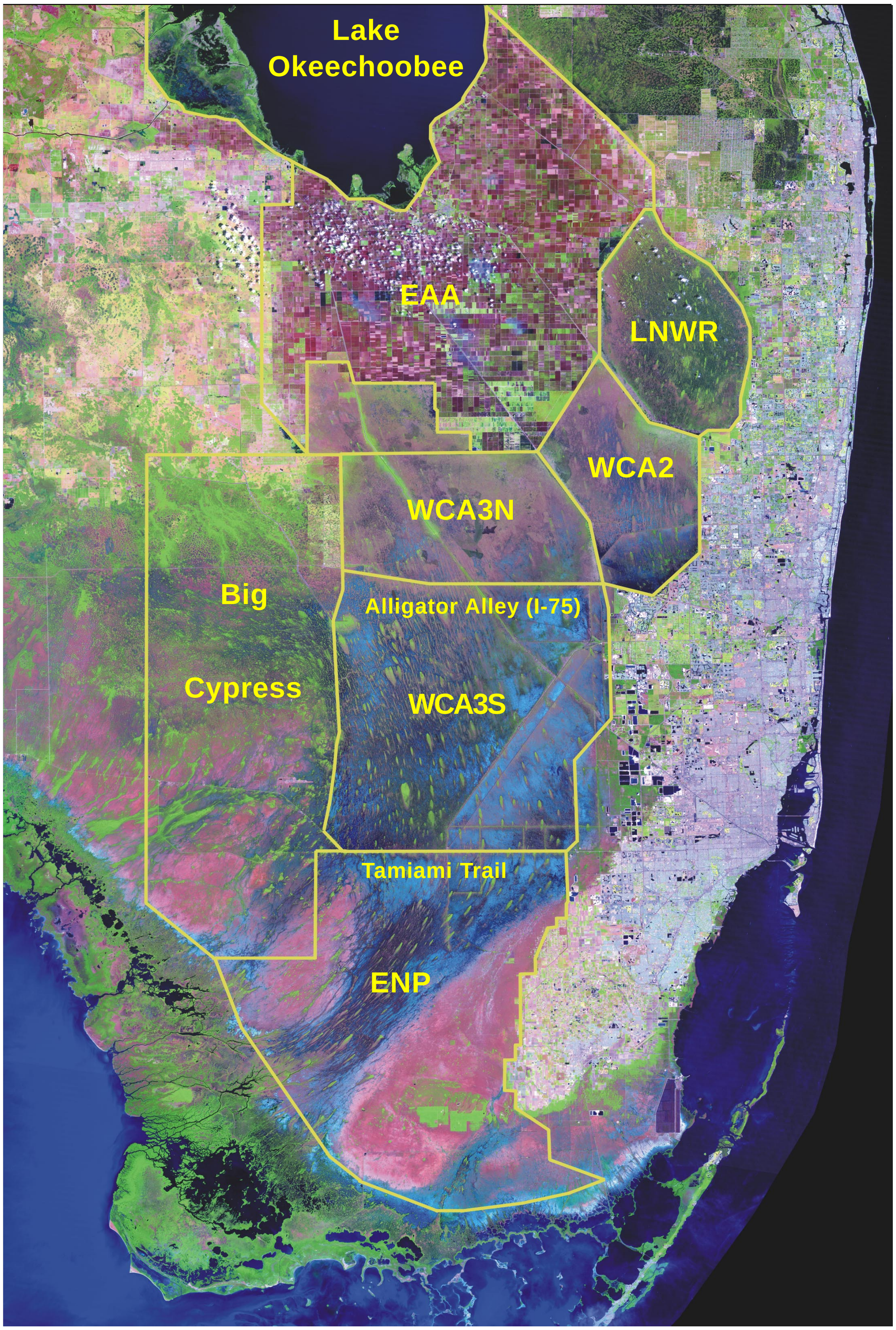


Figure 8. Satellite image of South Florida, circa 1995, with the areas sampled outlined in yellow: Everglades Agricultural Area (EAA); Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR); Everglades Water Conservation Area 2 (WCA2); Everglades Water Conservation Area 3 north of Alligator Alley (WCA3N); Everglades Water Conservation Area 3 south of Alligator Alley (WCA3S); the eastern portion of Big Cypress National Preserve (BCNP), and the freshwater portion of Everglades National Park (ENP). Light areas on the east indicate urban development.

During the last century, the Everglades has become subjected to multiple, often interrelated, environmental threats. Effective ecosystem protection and restoration requires addressing these threats holistically.

vegetables are grown on the peat soils of drained sawgrass marshes. Big Cypress National Preserve protects forested swamp resources along the western portion of the Everglades watershed.

Although one-third of the 16,000 square mile Everglades watershed is in public ownership, there are many environmental issues, often interrelated, that must be resolved to restore and protect the Everglades ecosystem. These include: water management; water supply conflicts; soil loss; water quality degradation and eutrophication; mercury contamination of gamefish, wading birds, and Florida panthers; habitat alteration and loss; protection of endangered species; and introduction and spread of nuisance exotic species.

THE COMPREHENSIVE EVERGLADES RESTORATION PLAN

The Central and Southern Florida Project has provided flood protection and water supply to people and agricultural lands, as intended. However, the Project has simultaneously altered the Everglades and the south Florida ecosystem. The Everglades no longer receives the proper quality or quantity of water at the right place or the right time. The remnant Everglades no longer exhibits the water regimes, vast area, and mosaic of habitats that defined the pre-drainage natural ecosystem. Wildlife habitat has been lost or changed, and the number of nesting wading birds (wood stork, great egret, snowy egret, tricolored heron, and white ibis) has decreased markedly during the twentieth century[4] (Figure 9). Historically, most water slowly flowed across or soaked into the region's vast wetlands. Today, over one-half of the region's wetlands

FIGURE 9. Everglades wading bird populations significantly declined during the 1900s.

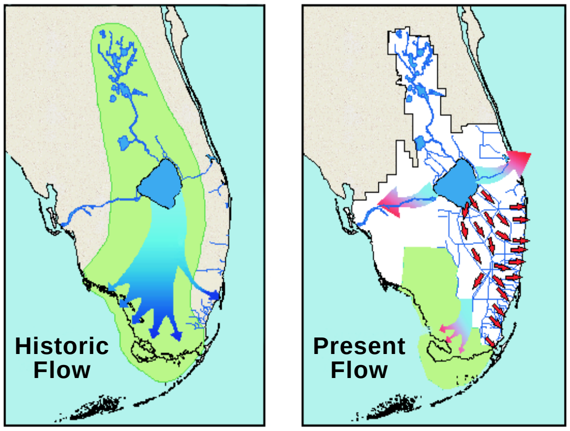


Figure 10. Historic (left) Everglades water flow patterns and present flow patterns (right)(adapted from 1, 5).

Figure 11. An extensive system of canals, levees, and water control structures has modified Everglades water conditions and provides a conduit for pollutant transport. This pump station discharges untreated stormwater from an urban basin into the Everglades.

have been irreversibly drained. The water storage and water quality filtration functions that these wetlands provided is gone. The canal system quickly drains water from developed areas and the wetlands that remain. On average, a billion gallons of fresh water are discharged to the coast each year. Discharges to the Everglades are frequently too much or too little, and are often at the wrong time (Figure 10). Some areas are too wet while other areas are too dry. Overland sheetflow is interrupted by levees and canals that crisscross the Everglades and can provide a conduit for pollutant transport from urban and agricultural areas (Figure 11). Nutrient enrichment has become a threat to the Everglades.

As the human population continues to increase, urban and agricultural water shortages are expected to become more frequent and severe. Conflicts for water between natural resources, agriculture, industry, and a growing population will therefore intensify.

The Solution

Many of the problems with declining ecosystem health revolve around four interrelated factors: water quantity, quality, timing, and distribution (Figure 12). Consequently, the major goal of restoration is to deliver the right amount of water that is clean enough to the right places and at the right time. Since water largely defined the natural system, it is expected that the natural system will respond to water management improvements (Figure 13). The Water Resources Development Acts of 1992 and 1996 directed the U.S. Army Corps of Engineers to review the Project and develop a comprehensive plan to restore and preserve

Figure 12. The right water quality, quantity, timing, and distribution of water are all critical to South Florida ecosystem protection and restoration[1].

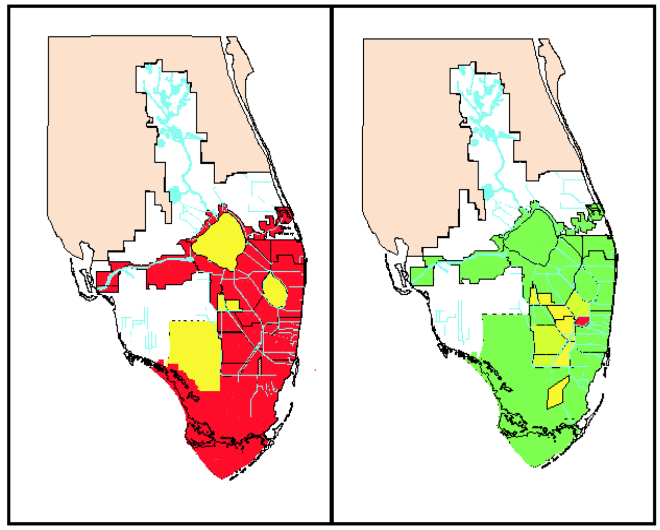


Figure 13. The anticipated effect of the Comprehensive Everglades Restoration Plan (CERP). Without the Plan (left) restoration targets will not be met (red). With the Plan fully implemented (right) restoration targets likely will be met (green). Yellow indicates uncertainty in meeting restoration targets[1].

south Florida's natural ecosystem, while providing for other water-related needs of the region including urban and agricultural water supply and flood protection. The result is the Comprehensive Everglades Restoration Plan (CERP, or the Plan). The development of the Plan was led by the Army Corps of Engineers and the South Florida Water Management District and was accomplished by a team of more than 100 ecologists, hydrologists, engineers and other professionals from over 30 federal, state, tribal, and local agencies. The Plan includes: about 180,000 acres of surface water storage areas; about 36,000 acres of man-made wetlands to treat urban or agricultural runoff; wastewater reuse; extensive aquifer storage and recovery; water management operational changes; and structural changes to improve how and when water is delivered to the Everglades, including removal of some of the canals or levees that prevent natural overland sheet flow. The entire Plan is projected to take over 30 years and cost about $8 billion to implement, with the cost split equally by Florida and the federal government. If nothing is done, the health of the Everglades will continue to decline, water quality will degrade further, some plant and animal populations will be stressed further, water shortages for urban and agricultural users will become more frequent, and the ability to protect people and their property from flooding will be compromised[1, 6].

A series of ecological success criteria have been defined that will gauge the success of ecosystem restoration efforts.

Example Everglades Ecosystem Restoration Success Indicators[7]

Problem	Success Indicators
Water Management	Reinstate system-wide natural hydropatterns and sheet flow
Habitat Alteration	Increased spatial extent of habitat and wildlife corridors
Eutrophication	Reduced phosphorus loading
Mercury Contamination	Reduced top carnivore mercury body burden
Endangered Species	Recovery of threatened/endangered species
Soil Loss	Restore natural soil formation processes and rates

To evaluate restoration success, we must have a reliable pre-restoration baseline for ecosystem condition.

USEPA REGION 4 SOUTH FLORIDA ECOSYSTEM ASSESSMENT PROJECT

The attention and funding devoted toward Everglades ecosystem restoration are unprecedented. It is imperative that ecosystem health is assessed in a cost-effective, quantitative manner such that baseline, pre-restoration conditions are documented. Such an assessment identifies resource restoration needs. Continued assessment allows one to determine the effectiveness of restoration efforts. A major defining feature of the Everglades is its large spatial area; hence, to monitor restoration it is essential to determine the area of the current Everglades that is subject to various human impacts. This study employs a scientifically rigorous way of accomplishing this, using a method called probability-based sampling.

Assessment information can be used to help answer seven policy-relevant questions:

1) *Magnitude* - What is the magnitude of the problem? How severe is it?
2) *Extent* - What is the extent of the problem? How large an area is affected?
3) *Trend* - Is the problem getting better, worse, or staying the same?
4) *Cause* - What factors are associated with or causing the problem?
5) *Source* - What are the contributions of and importance of different sources?
6) *Risk* - What are the risks to different ecological systems?
7) *Solutions* - What management alternatives are available to ameliorate or eliminate the problem?

These seven questions are equally applicable for each environmental problem threatening the Everglades, including water management, soil loss, eutrophication, habitat alteration and mercury contamination.

This project uses a statistical, probability-based sampling strategy to select sites for sampling. Samples were collected from the freshwater wetland portion of the Everglades and Big Cypress. The study area extended from Lake Okeechobee southward to the mangrove fringe on Florida Bay and from the ridge along the urban, eastern coast westward into Big Cypress National Preserve (Figure 8). The distribution of the 200 canal sample sites and the 500 marsh sample sites is shown in Figure 14. The samples represent the ecological condition in over 750 miles of canals and over 3,000 square miles of freshwater marsh. Canals were sampled in September 1993 and 1994, and May 1994 and 1995 (about 50 sites per sampling cycle). Marshes were sampled in April 1995, September 1995 and 1996, and May 1996 (about 125 sites per sampling cycle). This corresponds to two dry (April and May) seasons and two wet (September) seasons for both systems over a two-year period. Because the study involved sampling remote locations throughout an extensive area, each marsh sampling event was performed by two teams using helicopters equipped with floats. It took 8 or 9 days for the two teams to simultaneously sample 125 sites while moving from the south upstream to the north. A second phase of intensive sampling, performed at about 250 marsh sites during 1999, is described in companion reports. All reports and data for the study are available on the internet at <http://www.epa.gov/region4/sesd/sesdpub.html>.

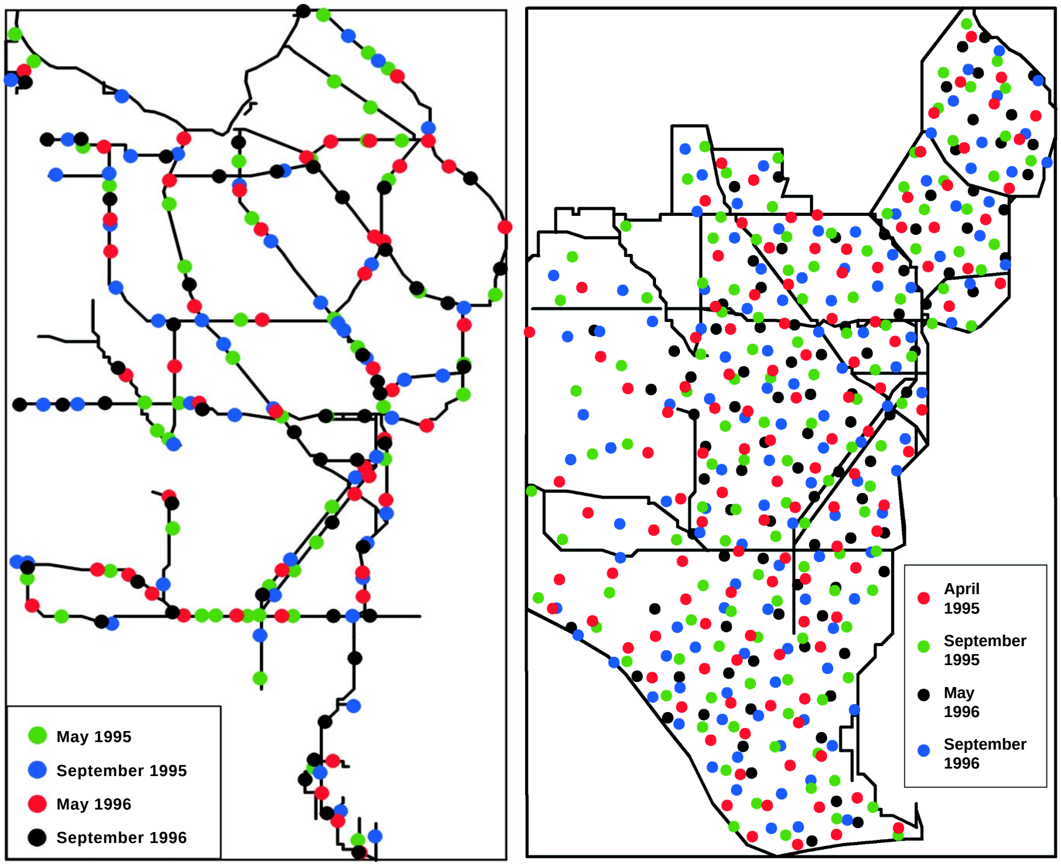


Figure 14. The 200 canal sampling stations (left) and 500 marsh sampling stations (right).

The media sampled at each site include surface water (Figure 15), canal sediment, marsh soil (Figure 16), algae (Figure 17), and prey fish (Figure 18). The study sampled three physiographic regions: Everglades ridge and slough; marl prairie/rocky glades; and Big Cypress Swamp.

This study permits a consistent, synoptic look at indicators of the ecological condition throughout the freshwater canal and marsh system. This large-scale perspective is critical to understanding the impacts of different factors (such as phosphorus and mercury distributions throughout the canals and marsh, habitat alteration, or hydropattern modification) on the entire system rather than at individual locations or in small areas. Looking only at isolated sites in any given area and extrapolating to the larger system can give a distorted perspective. This study is

Figure 15. Water samples were collected at each site and analyzed for nutrients, mercury, and other constituents.

Figure 16. A typical peat soil core collected from an Everglades wet prairie.

unique to South Florida: its extensive spatial coverage and sampling intensity are unprecedented; its probability-based sampling approach permits quantitative statements about ecosystem condition.

A key advantage to this study's probability-based statistical sampling approach is that it allows one to estimate, with known confidence and without bias, the current status and extent of indicators for the condition of ecological resources(8, 9). Also, indicators of pollutant exposure and habitat condition can be used to identify associations between human-induced stresses and ecological condition. This design has been reviewed by the National Academy of Sciences, and the USEPA has applied it to lakes, rivers, streams, wetlands, estuaries, forests, arid ecosystems and agro-ecosystems throughout the United States(10, 11).

Figure 17. Well-defined periphyton mats are a defining characteristic of the Everglades ridge and slough complex.

Figure 18. Sampling prey fish in a sawgrass marsh.

Probability Samples

A defining feature of the Everglades is its large spatial scale; hence, to monitor restoration effectiveness it is essential to determine the area of the Everglades that is subject to various human impacts. This study employs probability-based sampling in order to accomplish this. Probability samples are samples where every member of the population has a known chance of being selected and the samples are drawn at random. Every location in the study area has an equal chance of being sampled, so the results of this project are representative of the spatial distribution of parameters that are being measured. Therefore, the sampling design is not biased to favor one marsh type over another (e.g., sampling only the marshes next to a road because it is easier, avoiding sawgrass because it is unpleasant to sample in, or selecting a canal location because it looks good or bad). This means that the results can be used to estimate with known confidence the proportion (extent) and condition of that resource. The risk to any ecological resource from the multiple environmental threats in South Florida is a direct function of the extent and magnitude of both the threat and the ecological effects.

Parameters measured at each site can be used to answer questions on multiple issues including:

- Water management (e.g., water depth at all sites)
- Water quality and eutrophication (e.g., phosphorus concentrations in water and soil, cattail distribution)
- Habitat alteration (e.g., wet prairie, sawgrass marsh and cypress plant community distribution)
- Mercury contamination (e.g., mercury in water, soil, algae, and preyfish)

Specific questions related to Everglades restoration goals that this study answers include:

- How much of the marsh or canal system has a total phosphorus concentration greater than 50 parts per billion (ppb), the Phase I phosphorus control goal, or 10 ppb, the approximate natural marsh background concentration?
- How much of the marsh is dominated by sawgrass? Wet prairie? Cattail?
- How much of the marsh still has the natural oligotrophic periphyton mat?
- How much of the marsh area is dry, and where?
- How much of the marsh soil has been lost due to subsidence?
- How much of the marsh has prey fish with mercury levels that present increased risk to top predators such as wading birds?
- What water quality conditions are associated with marsh zones of high mercury bioaccumulation ?

The probability-based sampling design is an assessment approach that provides unbiased estimates of ecosystem condition with known confidence limits.

Data from this study have been used by a variety of scientists and agencies for many purposes:

- Input to models that predict the Everglades' response to water management changes.
- Input to models that predict periphyton or vegetation changes in response to phosphorus enrichment.
- Developing empirical models in order to better understand interrelationships among mercury, phosphorus, sulfur, and carbon.
- Developing water quality standards to protect human health, fish and wildlife.
- Understanding the relative risks of phosphorus and mercury.

Monitoring is important for determining ecosystem condition, identifying threats, and evaluating environmental restoration efforts. As portions of the Comprehensive Everglades Restoration Plan are implemented, a system-wide monitoring program is needed. Monitoring objectives include:

- Documenting status and trends;
- Determining baseline variability;
- Detecting responses to management actions;
- Improving the understanding of cause and effect relationships.

This South Florida Ecosystem Assessment Project provides such information system-wide for the freshwater Everglades marsh. The next sections describe ecosystem status based on the sampling program in canals and marshes from 1993 to 1996.

WATER MANAGEMENT

The historic Everglades was defined in part by water: highly seasonal rainfall; slow, unimpeded, sheetlike water flow; and a large storage capacity that prolonged wetland flooding. These characteristics, along with subtle changes in ground surface elevation of only a few feet, produced a variety of water depths and hydroperiods (duration of surface water inundation). Because changes in water caused many of the harmful changes to the historic Everglades, water is key to restoration. Rainfall and the general patterns in water depth observed from 1993 to 1996 are described in this section.

Rainfall is highly seasonal, with about 80% falling during the May to October wet season (Figures 19 and 20). Rainfall during the 1993-1996 sampling period was above average. Discharge through public water pumping stations is also highly seasonal. For example, at S-8, a pumping station that provides flood control for part

Figure 19. A typical intense rain event in the slough-wet prairie complex during the summer wet season.

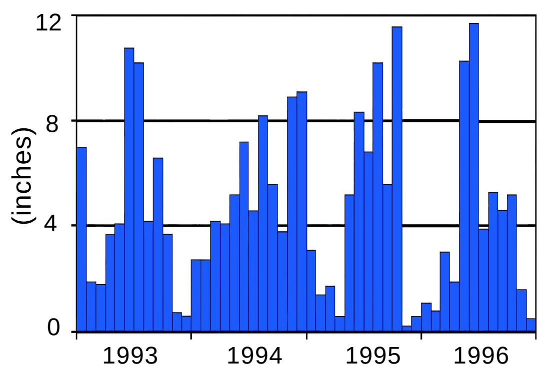


Figure 20. Monthly rainfall (inches) from 1993 to 1996 at S-8, a pumping station that provides flood control for part of the EAA by discharging into the Everglades.

Figure 21. The slough-wet prairie complex during the dry season.

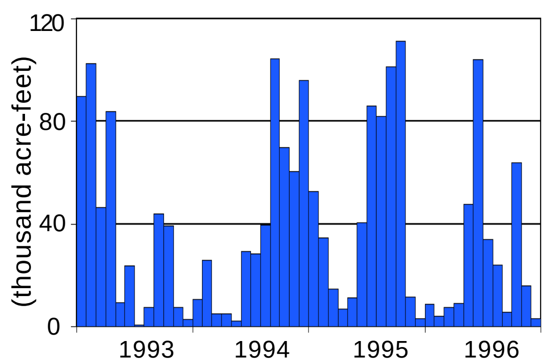


Figure 22. Monthly discharge at S-8. Discharge varies from zero to several thousand cubic feet per second in response to rain events.

of the Everglades Agricultural Area, discharge varies from zero during dry times to several thousand cubic feet per second in response to rain events (Figure 22).

Marsh water depths vary greatly with time and location (Figures 21, 23 to 25). Water depths are deepest immediately upstream of levees that impede the natural flow of water, such as the southern portions of Arthur R. Marshall Loxahatchee National Wildlife Refuge (the Refuge) and Water Conservation Areas 2 and 3A (Figure 23). Although all of these long hydroperiod areas remained wet during the study period, the unnaturally deep water depth of over five feet was observed within Water Conservation Area 3 where the L-67 levee prevents sheetflow to the south. Shorter hydroperiod portions of the marsh are subjected to annual periods of drying. During both wet seasons the entire marsh was inundated, while in April 1995 and May 1996 16% and 29% of the Everglades marsh was dry.

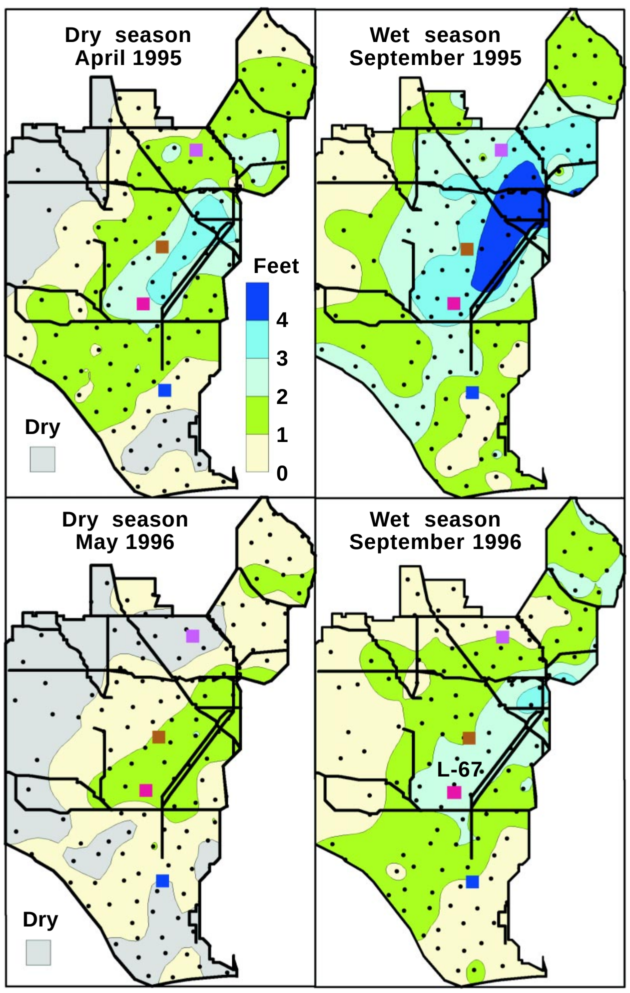


Figure 23. Water depth in the marsh system during the four sampling events. Colored squares indicate the location of water depth gauges used for Figure 24.

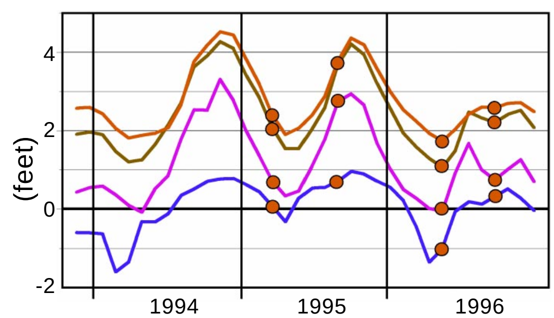


Figure 24. Mean monthly water depth at four marsh locations. Red circles indicate when sampling occurred. See Figure 23 for locations.

Figure 25. The slough-wet prairie complex during the wet season in Everglades National Park.

WATER QUALITY PATTERNS

Conductivity

Water conductivity is useful for understanding the source of the water and its flow path. Precipitation in the Everglades has very low ionic content, with specific conductivity of volume-weighted annual precipitation of about 10 micromhos/cm[12]. In contrast, the conductivity of water discharged from the EAA during the wet season is about 100 times higher (1,000 micromhos/cm). Conductivity exhibits pronounced seasonal and spatial patterns in the Everglades (Figures 26 and 27). Very low conductivity in Big Cypress, the western portions of Water Conservation Area 3A and the interior of the Refuge (less than 100 micromhos/cm) indicates that these areas are largely rainfall-driven. Higher conductivity water is transported downstream in canals draining the EAA, and there is a progressive decrease southward to the Park with dilution by rainfall and marsh water. Water Conservation Area 2 has the highest marsh conductivity. Marsh conductivity is higher in the dry season due to less dilution by

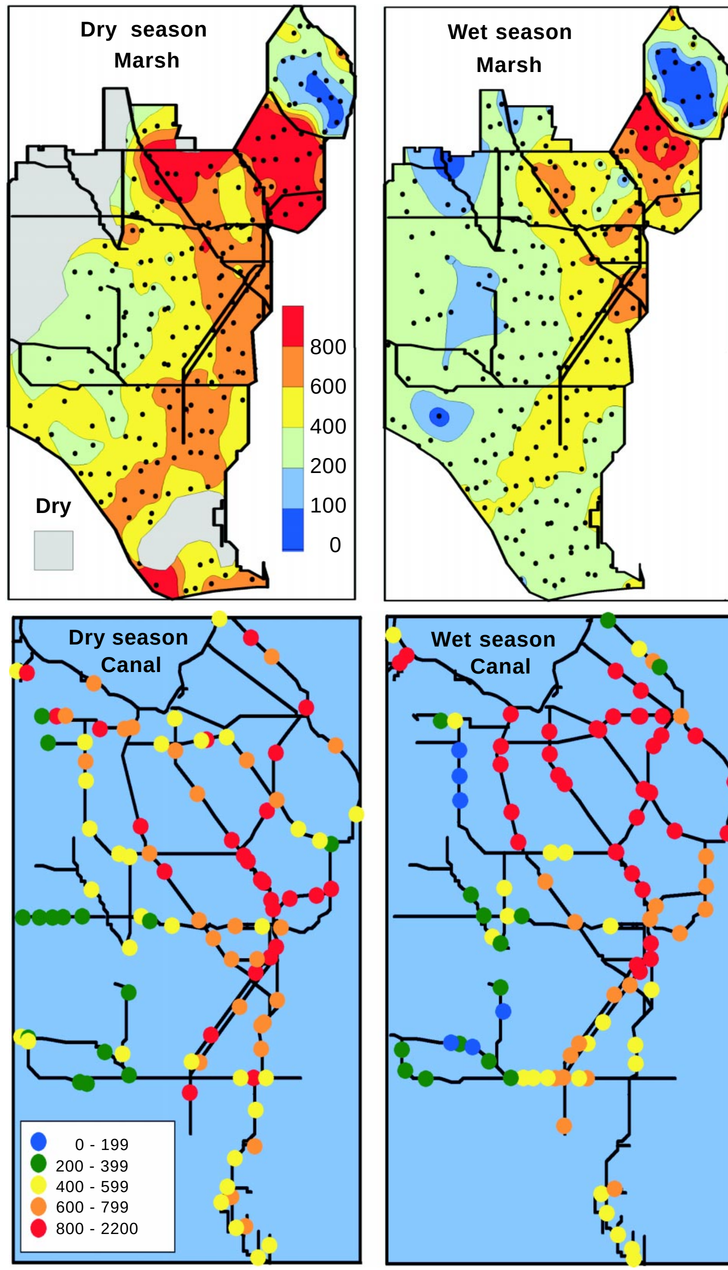


Figure 26. Surface water conductivity (micromhos/cm) in the marsh (top) and canals (bottom) during the dry season (left) and wet season (right).

rainfall, the drying of the marsh and subsequent evapoconcentration, and the continuing influence of canal water. Pronounced conductivity gradients clearly indicate pathways of water flow throughout the canal-marsh system and the extent to which the water management system and its operation influences water quality.

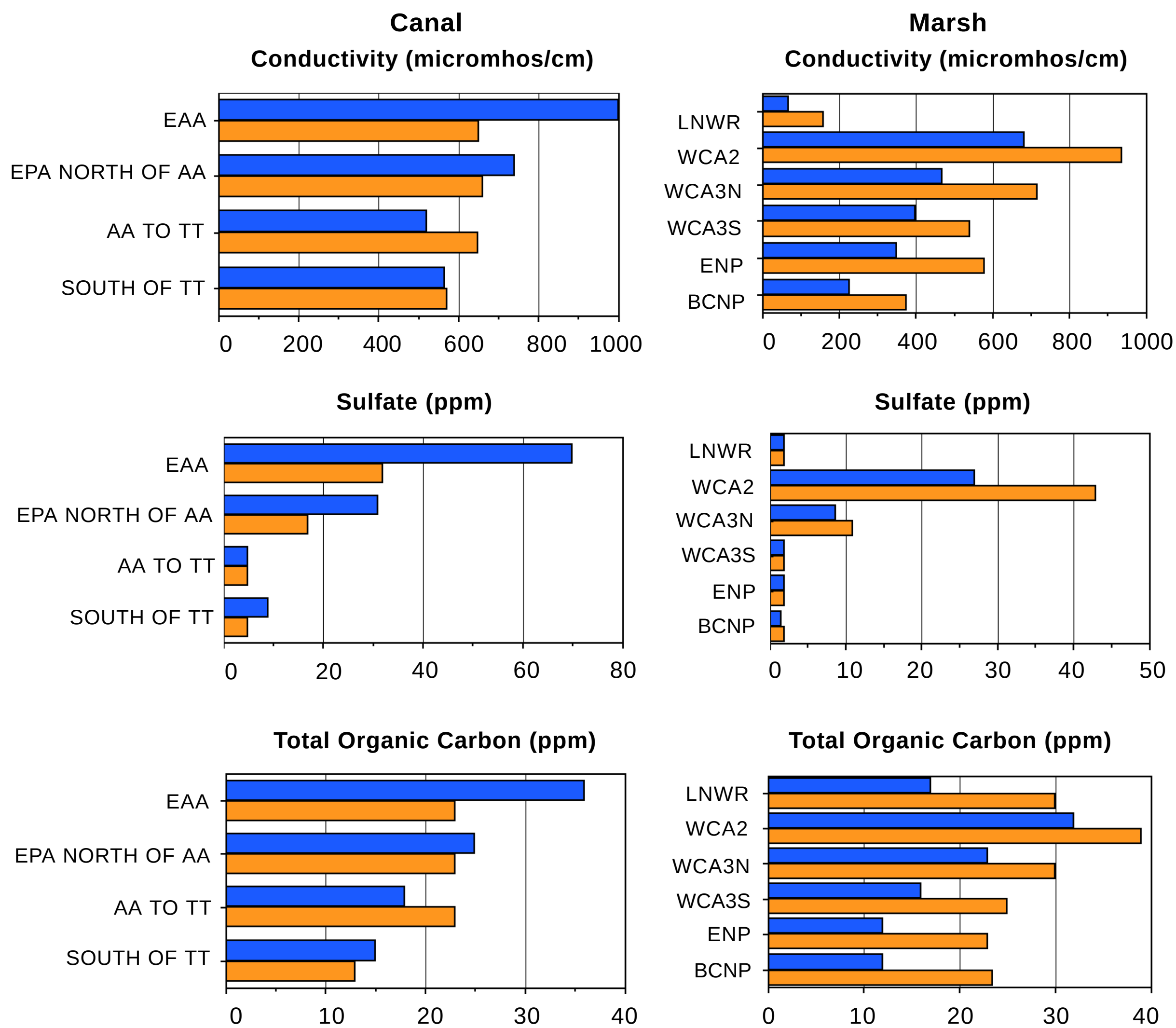


Figure 27. Seasonal comparison of surface water conductivity (micromhos/cm), sulfate (ppm) and total organic carbon (ppm) by latitudinal subarea for canals (left) and marsh (right). Blue bars are wet season, orange bars are dry season. EPA north of AA is the Everglades Protection Area north of Alligator Alley. WCA3N is WCA3A north of Alligator Alley. WCA3A S is WCA3B and WCA3A south of Alligator Alley. TT is Tamiami Trail. The median is reported.

Sulfate

Sulfate is common in nature and is a natural ingredient of rainfall, surface water and groundwater. Sulfur is also a secondary nutrient required for crops. Agricultural sulfur is applied to EAA soils in order to make plant nutrients more readily available[13, 14].

Marsh and canal surface water sulfate from 1993 to 1996 exhibited strong gradients and seasonality (Figures 27 and 28). Rainfall sulfate concentrations are less than 1 ppm[12]. Marsh background concentrations of less than 2 ppm are found only in the interior rainfall-driven portion of the Refuge, and portions of the marsh that are distant from the influence of canal water deliveries, such as western Water Conservation Area 3, Big Cypress, and portions of the Park. The highest sulfate concentrations of over 100 ppm were observed in canals within the EAA during the wet season. The highest marsh concentrations are found in Water Conservation Area 2. Concentrations progressively decrease to the south and west. The lowest concentrations are found in the Refuge, Big Cypress, and the marsh south of Tamiami Trail during the wet

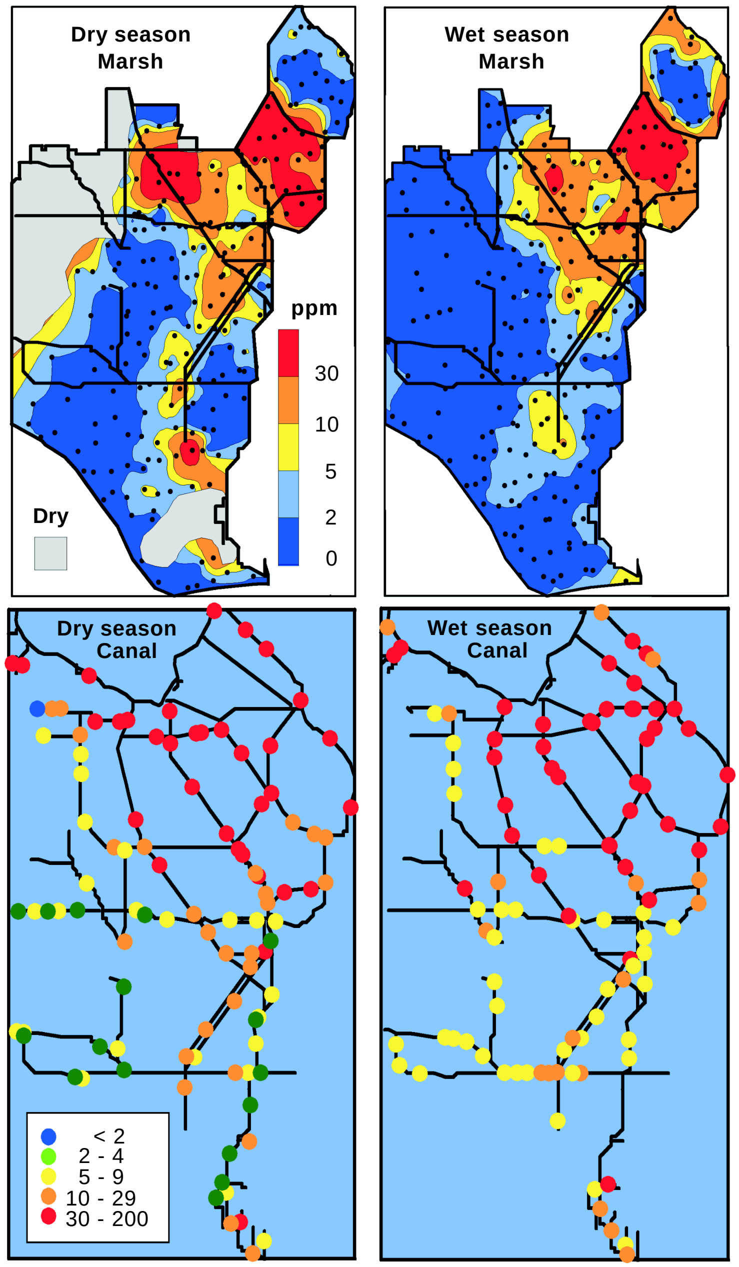


Figure 28. Surface water sulfate (ppm) in the marsh (top) and canals (bottom) during the dry season (left) and wet season (right).

Pronounced spatial gradients in surface water conductivity and sulfate throughout the canal and marsh system vividly demonstrate that the canal system is a conduit for transport. Water management affects water quality.

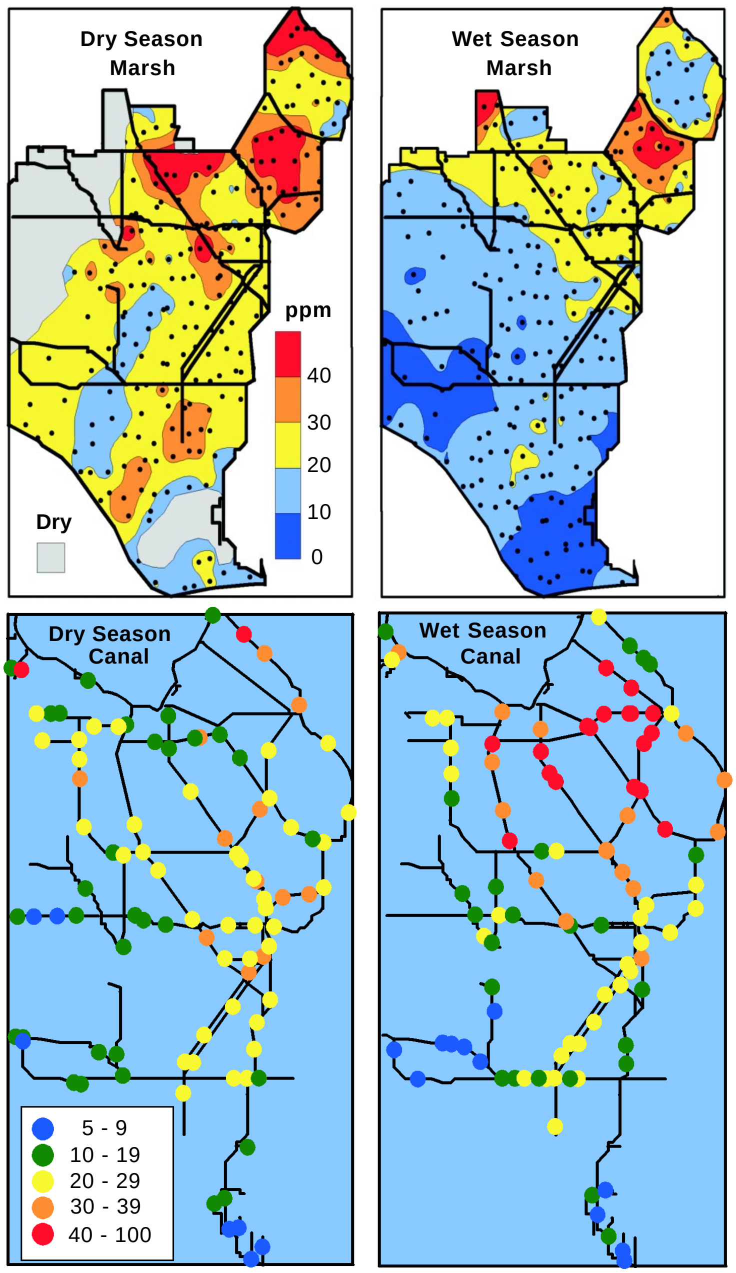


Figure 29. Surface water total organic carbon (ppm) in the marsh (top) and canals (bottom) during the dry season (left) and wet season (right).

season (median of less than 2 ppm).

These spatial patterns indicate that the canal system delivers sulfate from the north into Everglades marshes. Sulfate is of particular ecological concern since slightly elevated sulfate concentrations have been hypothesized to affect mercury cycling by stimulating mercury methylation(15).

Total Organic Carbon

The highest total organic carbon was observed in canals within the EAA (Figures 27 and 29). Total organic carbon also exhibits high seasonality with highest values during the dry season. Carbon is important in that it also plays a role in mercury cycling(15). The specific effects of carbon and sulfur on mercury cycling are the subject of ongoing research.

SOIL SUBSIDENCE

Soil is a key defining characteristic of an ecosystem, and soil preservation is an important aspect of ecosystem protection. The South Florida Ecosystem Restoration Task Force and the Comprehensive Everglades Restoration Plan have adopted objectives and success indices in order to define restoration goals, track ecosystem status, and measure restoration effectiveness. Among these is restoring the natural rates of organic soil and marl soil accretion, and stopping soil subsidence[(7)].

A variety of soil types are found in the Everglades. Soils to the west in Big Cypress Swamp are primarily sandy, while the wetland soils of the central Everglades are primarily organic peat (see Figures 5 and 16). Peat soils are formed by decaying plant matter. Another major soil type found within Everglades wetlands is a calcitic mud (marl), commonly found in the shallower peripheral marshes of the Everglades subjected to shorter periods of surface water inundation (Figure 30). Marl is found in association with thick algal mats, called periphyton, which are able to precipitate calcium carbonate from the water column[(16)].

The Everglades once contained the largest single body of organic soils in the world, covering over 3,000 square miles, and accumulating to a thickness of up to 17 feet in what is now the EAA[(17)]. The origin and perpetuation of peat and marl soils is greatly dependent upon water depth and the duration of surface water inundation, and the resulting wetland vegetative communities. Diminished surface water inundation can cause soil loss or changes in soil composition, which may in turn result in altered vegetative communities. These altered plant communities may cause further changes in soil type and thickness as this different plant community eventually decomposes and forms altered soil.

Figure 30. An Everglades soil core with peat overlaying marl.

Peat soils are subject to subsidence and surface elevation loss when drained. Oxidation, burning and compaction are considered the dominant subsidence forces, and from a practical standpoint are irreversible. An inch of Everglades peat that takes a century to form can be lost within a few years. Early in the twentieth century the deep peat soils (mostly formed by decaying sawgrass) of the 700,000 acre EAA were drained to facilitate agricultural production. The process of soil formation was reversed in 1906 when the first canals were cut from Lake Okeechobee through the EAA to the coast[18]. Subsequent subsidence within the EAA and efforts to control it on agricultural lands are well documented.

In contrast, prior to this study subsidence of peat soils during the last 50 years within the Everglades Protection Area was poorly documented. Soil loss in the public Everglades is largely due to water management practices during the 1900s. The major canals draining the EAA extend southeast through the Everglades to the Atlantic Ocean and were completed by 1917. However, unimpeded surface water flow from the EAA south through the Everglades to the Park, Florida Bay, and the Gulf of Mexico still occurred until the late 1950s, when levees were constructed forming the southern boundary of the EAA. During the early 1960s additional levees were completed that partitioned the Everglades into the Water Conservation Areas. By the 1960s Everglades surface water depths, flow, and inundation periods had been greatly altered[19].

Soil thickness measured at 479 sampling sites from 1995 to 1996 is presented in Figures 31 and 32, along with soil thicknesses reported by Davis in 1946[20]. Soil thicknesses throughout the study area vary greatly from 0 feet to over 12 feet. The deepest soils are the peat deposits within the Refuge with a median soil thickness of over 9 feet. Median soil thicknesses for remaining portions of the study area were 4.2 feet in Water Conservation Area 2, 1.2 feet in Water Conservation Area 3A north of Alligator Alley, 2.8 feet in Water Conservation Area 3 south of Alligator Alley, 1.0 feet in the Park, and 1.0 feet in Big Cypress. About 19% of the Everglades had a soil thickness less than one foot, while 40% had a soil thickness of over three feet. The deepest peat in the Everglades outside of the Refuge is within those portions of Water Conservation Area 2 and southern Water Conservation Area 3 which typically stay inundated year-round.

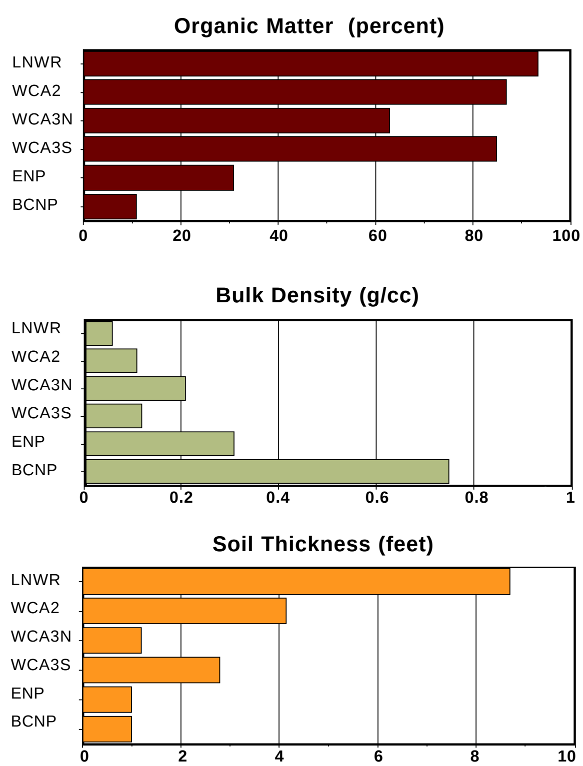


Figure 31. Spatial variation in soil organic matter, bulk density, and thickness throughout the Everglades marsh system at about 480 sampling sites. The median is reported.

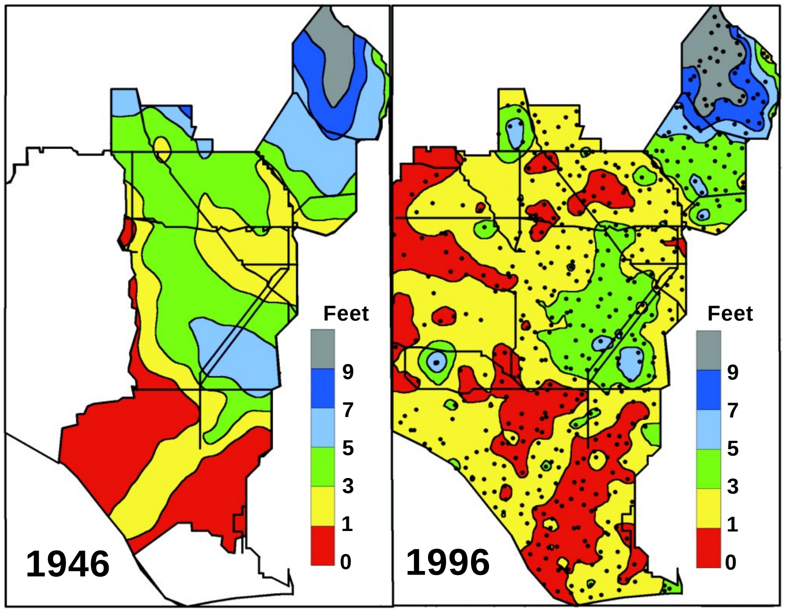


Figure 32. Soil thickness (feet) as reported by Davis in 1946 (left) and at 479 sites in 1995 to 1996 (this study).

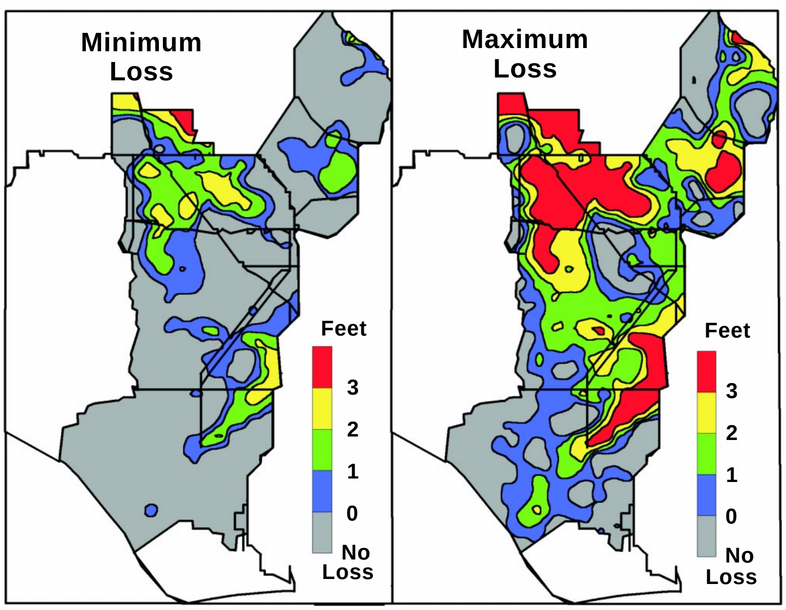


Figure 33. Soil loss (feet) from 1946 to 1996 for the Everglades.

Figure 33 presents the change in peat thickness throughout the Everglades during the last 50 years. Soil volumes reported in 1946 and 1996 and the difference have been calculated by subarea. Since the 1946 peat thickness was reported in 2-foot intervals, soil volume differences from 1946 to 1996 are presented as a range. Calculation of soil loss during the last 50 years indicates that the portion of Water Conservation Area 3 north of Alligator Alley lost between 39% and 65% (2.0 to 6.0 x 10^8 m^3) of its soil. This area was reported to have 3 to 5 feet of peat in 1946, while the present study found only 1 to 3 feet of soil, with less than 1 foot in some areas. The southeastern part of Water Conservation Area 3 (WCA3B) and the northeast Shark Slough portion of the Park may have lost up to 3 feet of soil, representing a 53% loss of volume in Northeast Shark Slough, and a 42% loss of volume in WCA3B. These three portions of the Everglades, which encompass about 200,000 acres, have been subjected to decreased surface water inundation since completion of the Water Conservation Areas about 40 years ago. During the last 50 years the Everglades Protection Area has lost up to 28% of its soil (17 x 10^8 m^3). The accretion of soil within portions of the Park suggested by Figure 33 may be an artifact of the 1946 sampling method. Davis (1946) mentions seven areas of detailed sampling, none of which were within what is now the Park.

Soil organic matter observed during 1995 and 1996 at 479 sites ranged from <1% to 97% (Figures 31 and 34). Peat soils are highly organic, while marl soils and sandy soils are primarily mineral. The highest organic matter content was found in the thick peat soils within the Refuge with a median of 93%. Water Conservation Area 2A and Water Conservation Area 3 south of Alligator Alley also had soils exceeding 75% organic matter. These highly organic zones coincide with the deeper soil portions of the system. The area of maximum soil loss within Water Conservation Area 3 north of Alligator Alley had a median soil organic matter content

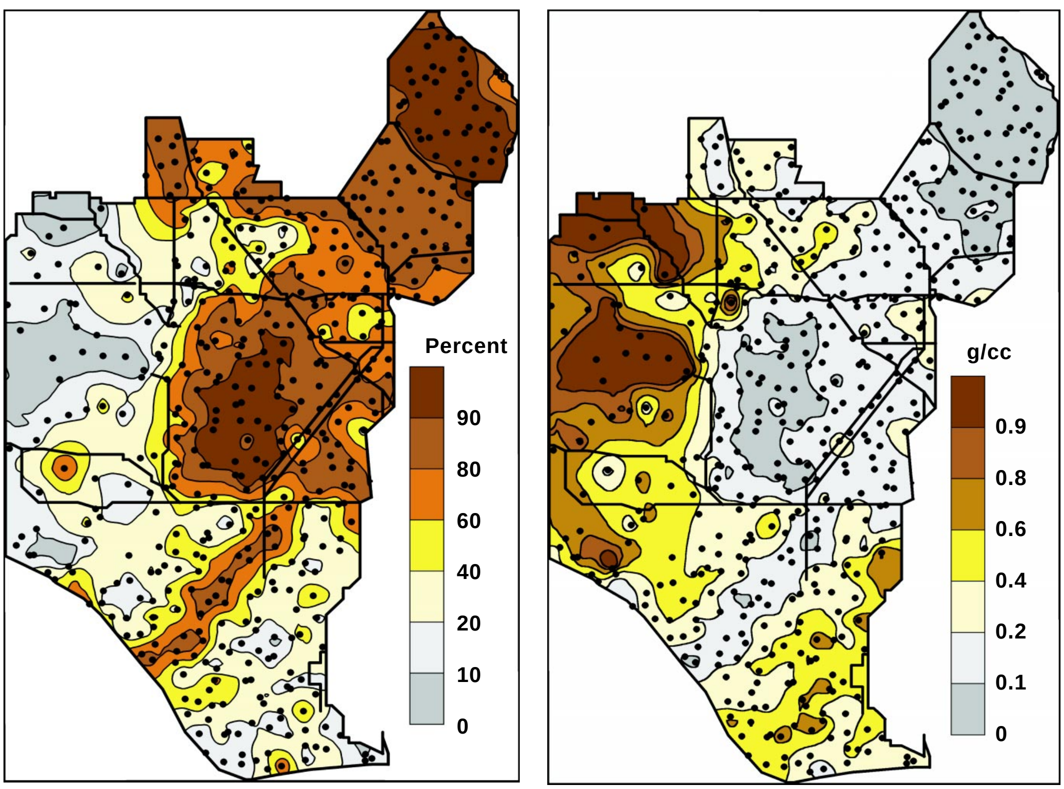


Figure 34. Soil organic matter (percent, left) and bulk density (g/cc, right). Data are for the 0 to 10 cm soil depth.

During the last 50 years, over one-half of the soil has been lost from portions of the Everglades. Water management must be improved to maintain marsh soils if the plant communities and wildlife habitat of these wetlands are to be preserved.

of 63%, the lowest within the Water Conservation Areas. Soils in the Park, which include the peat soils within the Shark Slough trough as well as the marl soils of adjacent shorter hydroperiod areas, had a median organic content of 31%. The sandy soils of Big Cypress had a median organic matter content of only 11%. Portions of the Park outside the central Shark Slough trough also had lower organic matter content, usually in the 10% to 20% range.

Soil bulk density at 475 marsh sites in 1995 and 1996 ranged from 0.05 to 1.50 g/cc (Figures 31 and 34). The highly organic peat soils of the Refuge had the lowest bulk density with a median of 0.06 g/cc as compared to the mineral soils of Big Cypress, which had a median of 0.75 g/cc. The median bulk density for Water Conservation Area 3 north of Alligator Alley was 0.21 g/cc, the highest in the Water Conservation Areas. Within the Water Conservation Areas, this portion of northern Water Conservation Area 3 had the lowest organic matter content, the highest bulk density, and the greatest soil loss.

All of these observations are suggestive of formerly deeper peat soils being subjected to drier conditions due to water management changes over the last 50 years. Surface water inundation has been reduced, soils have subsided, and the resulting surface soil has become less organic. This South Florida Ecosystem Assessment Project is the first effort to consistently document soil thickness, bulk density and organic matter throughout the Everglades system.

EUTROPHICATION AND HABITAT

Historically, the Everglades ecosystem was nutrient poor, with surface water phosphorus concentrations less than 10 parts per billion (ppb)[21]. Rainfall was the dominant source of external phosphorus, and the hydrology of the marsh was rainfall-driven, with slow overland sheet flow supplying water to downstream wetlands. There were no canals in the Everglades region prior to the early part of the twentieth century. This natural nutrient-poor condition resulted in a diversity of wildlife habitats, such as sloughs, sawgrass marshes, and wet prairies which included well-developed periphyton communities.

Today, the canal system is a conduit for nutrient transport. Nutrient loading from the EAA and urban areas has significantly increased phosphorus concentrations in the downstream Water Conservation Areas and the Park, causing eutrophic impacts to these wetland systems. Among the progressive eutrophic impacts are altered periphyton communities, loss of water column dissolved oxygen, increased soil phosphorus content, conversion of wet prairie and sawgrass plant communities to cattail, and subsequent loss of important wading bird foraging habitat. These collective changes impact the structure and function of the aquatic ecosystem.

A phosphorus control program was initiated in the 1990s in order to prevent the further loss of Everglades plant communities and wildlife habitat due to nutrient enrichment. Phase I of the program requires that discharges from the EAA into the Everglades be at 50 ppb total phosphorus (TP) or less. Control is to be achieved by a combination of about 47,000 acres of treatment wetlands, referred to as Stormwater Treatment Areas (STAs) (Figure 35), and agricultural Best Management Practices (BMPs). The first STA (about 10% of the Phase I treatment acreage) began discharging in 1994, and BMPs were required to be in place by 1995. The 1993 to 1996 sampling period reported here corresponds to the phase-in period for EAA BMPs, as during these years the percentage of EAA farms with phosphorus control BMPs in place went from 0 to 100. The BMPs have resulted in about a 50% three-year cumulative phosphorus load reduction from the EAA basin to the Everglades Protection Area, as compared to the load that would have been expected without BMPs[22]. This report documents the 1993 to 1996 phosphorus conditions and habitat during the initiation of phosphorus control efforts.

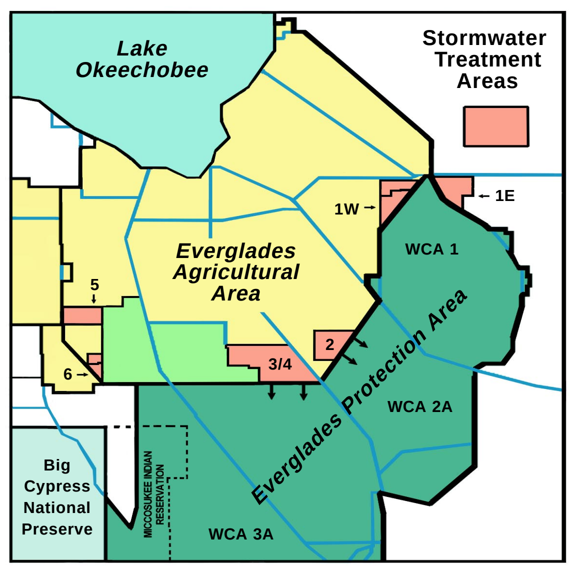


Figure 35. Location of Phase I phosphorus control program stormwater treatment wetlands. In combination with agricultural best management practices they are to decrease phosphorus to 50 ppb or less prior to discharge into the Everglades (adapted from SFWMD).

Water and soil samples were analyzed for phosphorus and other indicators of nutrient enrichment, such as nitrogen, chlorophyll *a*, and alkaline phosphatase activity. Relationships between phosphorus concentrations in water and soils, plant communities, and periphyton presence were noted to identify correlations between nutrient enrichment and habitat in the Everglades ecosystem.

Canal TP concentrations exhibit strong north to south gradients. Concentrations in EAA canals were significantly higher than those in any other area sampled (Figures 36 and 37), with a wet season median of 149 ppb (as compared to 13 ppb in canals near the Park). About 80% of the canal miles in the EAA had TP concentrations greater than the Phase I STA design target of 50 ppb. This drops to 15% for canals in the area between Alligator Alley and Tamiami Trail, and to only 1% for canals in the area south of Tamiami Trail. North of Alligator Alley wet season concentrations tend to be higher, while to the south dry season concentrations tend to be higher. Overall, 44% of canal miles had water TP concentrations greater than 50 ppb.

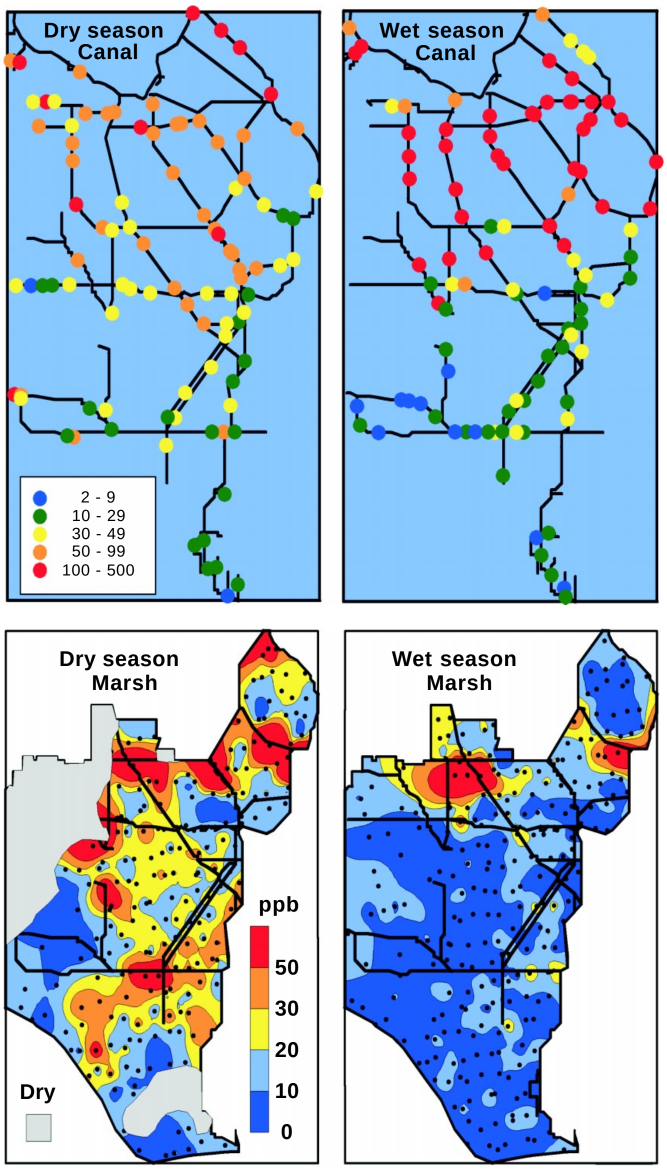


Figure 36. Surface water total phosphorus (ppb) in the marsh (top) and canals (bottom) during the dry season (left) and wet season (right).

Marsh sites also exhibit spatial gradients. Marsh TP concentrations were notably higher in the dry season, with the highest concentrations most consistently occurring in northeast Water Conservation Area 2A. The interior of the Refuge tended to have very low concentrations, indicative of its rainfall-driven status (Figures 36 and 37). Median TP concentrations throughout the Everglades system ranged from less than 10 ppb in the marsh during the wet season (Figure 38), to almost 50 ppb in the canals during the dry season.

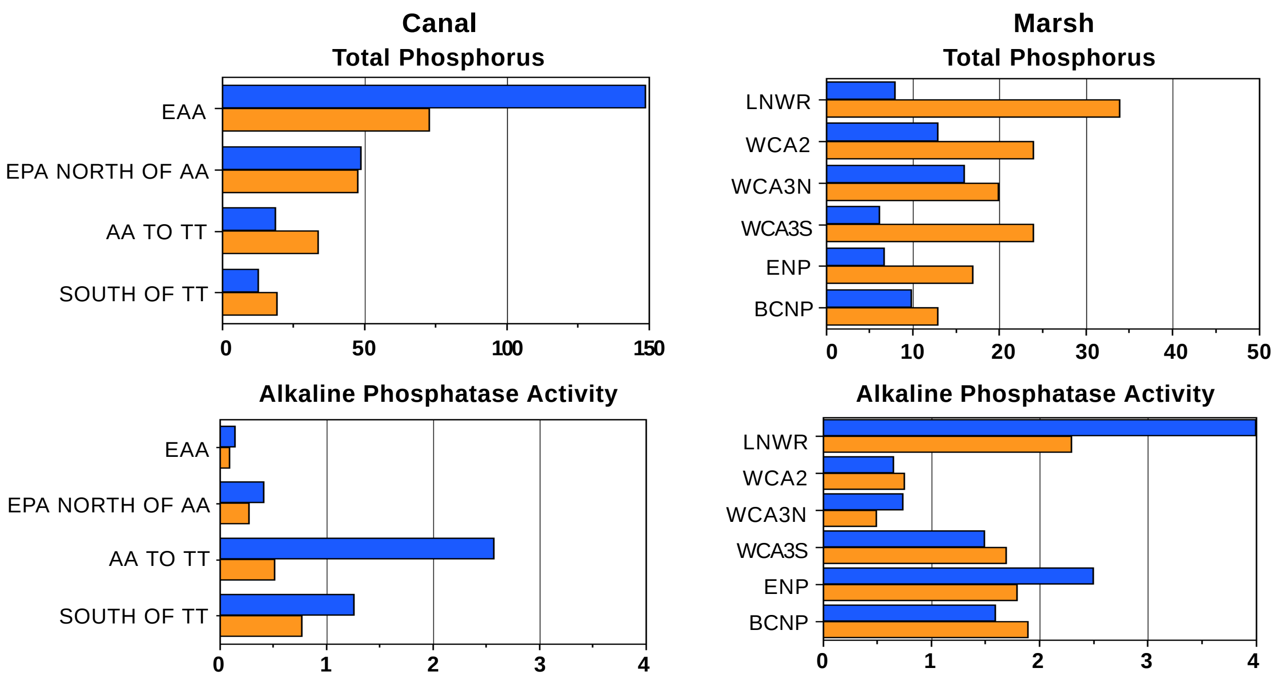


Figure 37. Seasonal comparison of surface water total phosphorus (ppb) and alkaline phosphatase activity (micromoles/hr) by latitudinal subarea for canals (left) and marsh (right). Blue bars are wet season, orange bars are dry season. Alkaline phosphatase is an enzyme that makes phosphorus available for biological uptake. Lower activity is indicative of higher phosphorus availability. EPA north of AA is the Everglades Protection Area north of Alligator Alley. WCA3 N is WCA3A north of Alligator Alley (AA). WCA3 S is WC3B and WCA 3A south of Alligator Alley. TT is Tamiami Trail. The median is reported.

Similar patterns existed for alkaline phosphatase activity (APA) (Figures 37 and 39). Alkaline phosphatase is an enzyme that makes phosphorus available for biological uptake. Higher activity indicates low phosphorus concentration. In general, APA throughout the marsh and canals exhibited strong gradients and the expected inverse relationship with TP in water. The lowest enzyme activities (median of

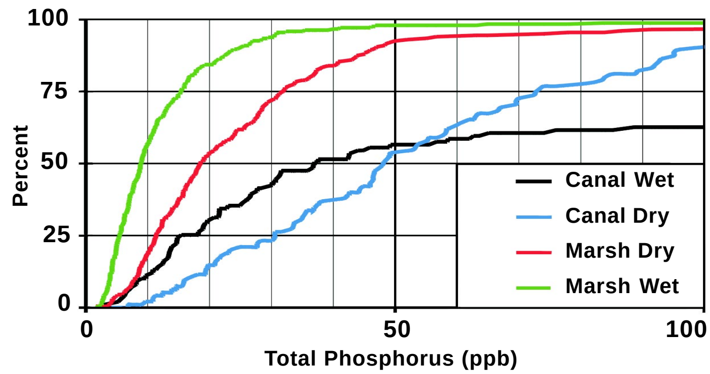


Figure 38. Cumulative distribution of frequency for total phosphorus by season in the marsh and canal systems. The y-axis indicates percent of canal miles or percent of marsh area. The 50% line is the median.

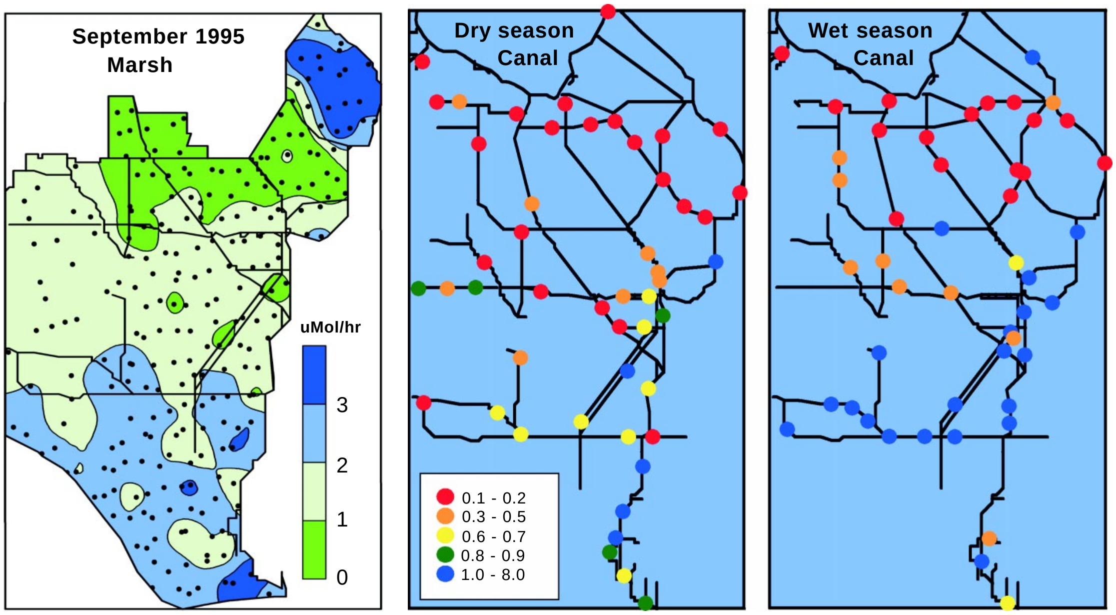


Figure 39. Surface water alkaline phosphatase activity (micromoles per hour) in the marsh (left, September 1995) and canals. Canal data are for dry season (middle) and wet season (right).

about 0.1 micromoles/hr) were observed in EAA canals where water TP concentrations were highest. The highest enzyme activities were found during the wet season in the Refuge (median of 4.2 micromoles/hr) and interior portions of the Park (median of 2.5 micromoles/hr).

Phosphorus in marsh soils can be an indicator of enrichment. Soil type varies greatly throughout the Everglades, as the median bulk density of soil varied from about 0.06 g/cc in the Refuge to 0.75 g/cc in Big Cypress (Figure 34). Soil phosphorus is expressed in Figure 40 as milligrams phosphorus per kilogram of soil, and as micrograms phosphorus per cubic centimeter of soil in order to remove the influence of varying soil bulk density. Depicted in this manner, Water Conservation Area 3A north of Alligator Alley and northern Water Conservation Area 2A have the highest soil phosphorus in the portion of the Everglades with peat soil. In contrast, the Refuge interior has much lower soil phosphorus than any other part of the system. Results reported here for 1995 to 1996 are similar to those obtained by others in the early 1990s for the Refuge and Water Conservation Areas 2 and 3[21]. This study is the first to perform systematic synoptic sampling of soil phosphorus throughout all of the Everglades Protection Area and Big Cypress.

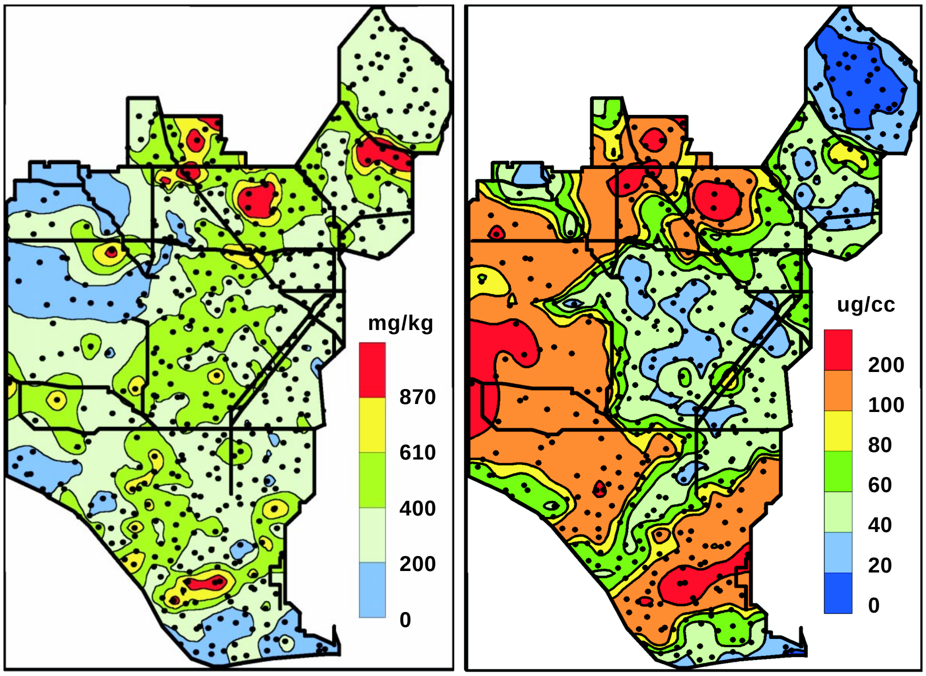


FIGURE 40. Soil total phosphorus expressed as milligrams per kilogram (left) and as micrograms per cubic centimeter (right). Data are for the 0 to 10 centimeter soil depth.

The natural mosaic of vegetation community types is a defining characteristic of the Everglades. Wet prairies and open water areas void of dense emergent macrophytes serve as preferred wading bird foraging habitat. Factors driving vegetation community composition include hydroperiod, salinity, nutrients, and disturbances such as fire, frosts, and hurricanes. Field crews documented the dominant and secondary plant communities at the marsh sampling sites. A simple vegetation classification method was used to qualitatively group marsh habitat into several classes, including sawgrass marsh and wet prairie. Field crews also noted if cattail (*Typha domingensis*) was present at a site. Cattail is a native species known to respond to phosphorus enrichment such that it can replace wet prairies and sawgrass.

Wet prairie and sawgrass marsh are the two dominant plant communities in the Everglades. Sawgrass was dominant at 47% of the 479 sampling sites and the wet prairie-slough complex was dominant at 44% of the sites (Figures 41 to 43). Wet prairie tends to dominate in the Refuge, and in wetter portions of WCA3. Sawgrass tends to dominate north of Alligator Alley and in Water Conservation Area 2, while the Park contains a mix of the two communities. Cattail presence along with soil phosphorus is shown in Figure 43. Cattail was present at 10% of the sampling sites.

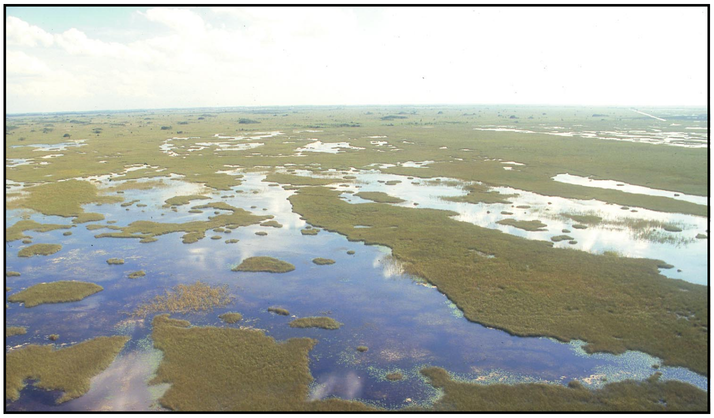


Figure 41. Aerial view of the Everglades showing the mosaic of sawgrass marsh and wet prairie plant communities.

Figure 42. Sawgrass marsh with high plant density.

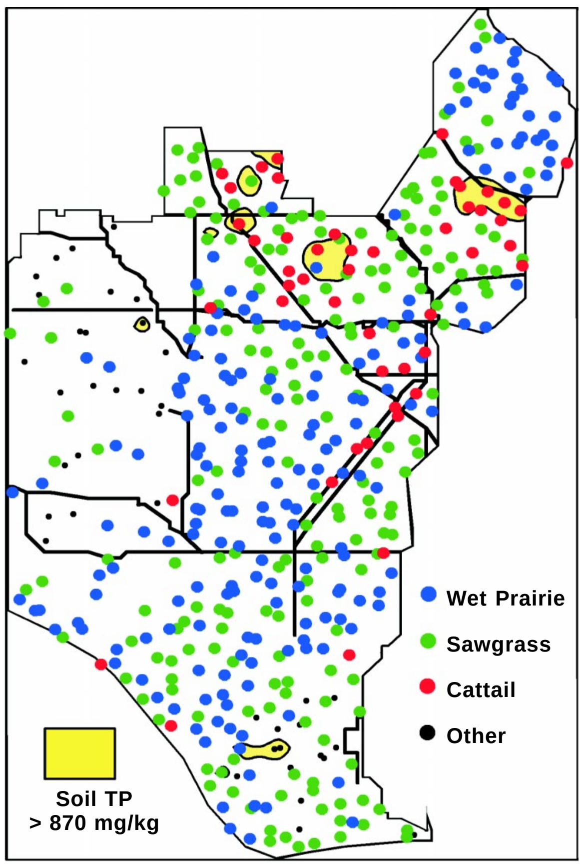


Figure 43. The spatial distribution of the wet prairie (blue) and sawgrass marsh (green) vegetation communities. Red indicates the presence of cattail. Yellow indicates soil phosphorus greater than 870 mg/kg [23].

Cattail was prevalent in the northern portions of Water Conservation Areas 3A and 2A, and sites that were generally in close proximity to canals. There tends to be a strong association between cattail presence and soil phosphorus or proximity to canals. As soil phosphorus increases, there is a greater likelihood that cattail will be present[23].

Figure 44. Everglades eutrophication promotes cattail expansion.

Low phosphorus conditions must be restored if natural Everglades periphyton and plant communities are to be maintained.

Well-developed attached or floating periphyton mats are a defining characteristic of Everglades habitats, particularly wet prairies and deeper slough areas (Figures 2, 17, 45 and 46). These biologic communities serve multiple functions such as providing oxygen to the water column for fish, removing calcium carbonate from the water and depositing it as soil, removing phosphorus from the water to very low levels, and serving as a food web base[21]. These periphyton communities are sensitive to very slight increases in nutrient concentration, with increases in phosphorus condition causing mat disappearance or changes to the periphyton assemblage, including species composition and biomass. Consequently, periphyton are a sensitive indicator of marsh ecosystem status.

Periphyton mats were found at 67% of the sample sites during 1995-1996. The species composition of these mats was not documented. Mats were less common in the Refuge and the northern portions of Water Conservation Areas 2A and 3A (Figure 46). With the exception of the Refuge, the areas where periphyton mats were not found tend to be areas where wet prairies are absent and sawgrass or cattail dominate. In communities where plant density, height, and above ground biomass are high, shading effects may preclude the development of periphyton mats and wet prairie communities. Elevated phosphorus may also explain the absence of the mat community, or a change in periphyton species composition to species that are more nutrient tolerant[21].

FIGURE 45. Underwater view of a wet prairie in southern Water Conservation Area 3 with periphyton attached to macrophytes.

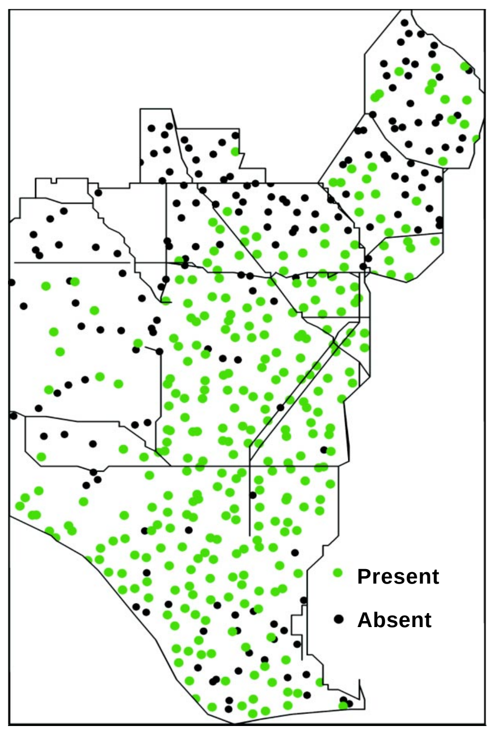


FIGURE 46. Presence of a periphyton mat community. Green indicates presence while black indicates absence.

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

This report describes the condition of the Everglades system during the extensive 1993 to 1996 synoptic sampling effort. This represents the condition prior to initiation of the Comprehensive Everglades Restoration Program. Study findings have various management implications.

- ***Pronounced water quality gradients:*** Water discharged from Everglades Agricultural Area canals is loading the public Everglades with excess phosphorus, carbon, and sulfur. Concentrations progressively decrease downstream.

- ***Canals are a conduit for pollutant transport:*** The canal system is an effective conduit for the transport of degraded water into and through the Everglades marsh system. Water management clearly affects water quality. Downstream water quality would be improved if delivery canals were eliminated or if they were operated to maximize the diluting influence of rainfall, cleaner marsh water and surface water sheetflow.

- ***Varying water quality:*** Surface water conductivity, phosphorus, carbon, nitrogen and sulfur vary greatly throughout Big Cypress and the Everglades and are dependent upon location, time of year and water management practices. Long-term sampling is required in order to differentiate between natural seasonality, inter-annual variability, and the effects of specific restoration actions taken under the adaptive assessment approach.

- ***Phosphorus enrichment:*** As of 1995 to 1996, about 44% of the Everglades canal system and 4% of the Everglades marsh area had total phosphorus concentrations exceeding the Phase I 50 part per billion control target. Once all phosphorus control efforts are in place (2007), probability-based sampling can be repeated to document the effectiveness of these efforts.

- ***Marsh habitat a mosaic:*** Wet prairie and sawgrass marsh were the two dominant plant communities in the Everglades, representing 44% and 47% of the sites sampled. Cattail was present at 10% of these sites, and was associated with elevated soil phosphorus or proximity to canals. Water quantity and water quality must be managed to maintain these important habitats, and halt further encroachment of cattail.

- ***Periphyton conspicuous:*** Well-defined periphyton mats, a defining characteristic of the Everglades marsh complex, were found at 67% of the sample sites. Water quality should be maintained such that oligotrophic periphyton mats are perpetuated.

- ***Soil loss in the Everglades Protection Area:*** From 1946 to 1996, about one-half of the peat soil was lost from drier portions of the Everglades. This is a serious problem that must be addressed. Water management must be improved to maintain remaining marsh soils if the plant communities and wildlife habitat of these wetlands are to be preserved.

- ***Ecological condition varies by location and time:*** The ecological condition of the Everglades varied greatly with location. Rainfall-driven portions of the system that are distant from the influence of canal water, such as the interior of Arthur R. Marshall Loxahatchee National Wildlife Refuge and the southwest portion of Water Conservation Area 3A, were found to have good water quality and low soil phosphorus. The interior of Loxahatchee National Wildlife Refuge tended to have the most pristine water quality and the lowest phosphorus concentrations in peat soils. In contrast, northern Water Conservation Area 3A had poorer water quality, extensive soil loss due to water management, elevated soil phosphorus and cattail encroachment. Water Conservation Area 2 had evidence of phosphorus enrichment and cattail encroachment, along with high sulfate and conductivity. Big Cypress had good water quality and no obvious indications of phosphorus enrichment. Water quantity conditions at a given location vary with season and year.

- ***Environmental threats interrelated:*** Ecological stressors such as water management, soil loss, water quality degradation, eutrophication, cattail encroachment and mercury contamination are often interrelated. Management actions must be holistic.

This project provides a critical benchmark for assessing the ecosystem condition and the effectiveness of Everglades restoration activities into the twenty-first century. As Everglades protection efforts proceed, this probability-based sampling can be repeated to document the effectiveness of these actions.

The South Florida Ecosystem Assessment Project documents conditions in the Everglades prior to ecosystem restoration efforts. This provides a benchmark for determining the effectiveness of future Everglades restoration activities.

REFERENCES

References Cited

1. United States Army Corps of Engineers and South Florida Water Management District. July 1999. Rescuing an Endangered Ecosystem: the Plan to Restore America's Everglades. The Central and Southern Florida Project Comprehensive Review Study (The Restudy). 28 p. <http://www.evergladesplan.org/>

2. United States Bureau of the Census. 1890 to 1990 United States census results.

3. Davis, Steven M. and John C. Ogden. 1993. Everglades: The Ecosystem and Its Restoration. St. Lucie Press. Delray Beach, Florida. 826 p.

4. Ogden, John C. 1993. A Comparison of Wading Bird Nesting Colony Dynamics (1931-1946 and 1971-1989) as an Indication of Ecosystem Conditions in the Southern Everglades. pp. 533-570 *in* Everglades: The Ecosystem and Its Restoration. Davis, Steven M. and John C. Ogden (editors). St. Lucie Press. Delray Beach, Florida. 826 p.

5. Ingebritsen, S. E., Christopher McVoy, B. Glaz, and Winfred Park. 2000. Florida Everglades. pp. 95-106 *in* Land Subsidence in the United States. Devin Galloway, David R. Jones and S. E. Ingebritzen, editors. United States Geological Survey Circular 1182. Denver, Colorado. 177 p.

6. United States Army Corps of Engineers and South Florida Water Management District. October 1998. Overview. The Central and Southern Florida Project Comprehensive Review Study. 29 p. <http://www.evergladesplan.org/>

7. Science Subgroup. 1997. Ecologic and Precursor Success Criteria for South Florida Ecosystem Restoration. Report to the Working Group of the South Florida Ecosystem Restoration Task Force. Planning Division. United States Army Corps of Engineers. Jacksonville, Florida. < http://www.sfrestore.org/>

8. Thornton, K. W., Saul, G. E. and Hyatt, D. E. 1994. Environmental Monitoring and Assessment Program Assessment Framework. United States Environmental Agency Report EPA/620/R-94/016. Research Triangle Park, North Carolina. 47 p.

9. Stevens, Don L., Jr. 1997. Variable Density Grid-based Sampling Designs for Continuous Spatial Populations. Environmetrics vol. 8, p. 167-195.

10. Olsen, A. R., Sedransk, J., Edwards, D., Gotway, C. A., Liggett, W. 1999. Statistical Issues for Monitoring Ecological and Natural Resources in the United States. Environmental Monitoring and Assessment, vol. 54, p. 1-45.

11. United States Environmental Protection Agency. 1995. Environmental Monitoring and Assessment Program (EMAP) Cumulative Bibliography. United States Environmental Protection Agency, Office of Research and Development. EPA/620/R-95/006. Resarch Triangle Park, North Carolina. 44 p.

12. National Atmospheric Deposition Program. 2000. National Atmospheric Deposition Program data, site FL11. <http://nadp.sws.uiuc.edu/default.html> Accessed July 19, 2000.

13. Coale, Frank J. 1994. Sugarcane Production in the EAA. pp. 224-237 *in* Everglades Agricultural Area (EAA): Water, Soil, Crop, and Environmental Management. University Press of Florida. Gainesville, Florida. 318 p.

14. Schueneman, T. J. and C. A. Sanchez. 1994. Vegetable Production in the EAA. pp. 238-277 *in* Everglades Agricultural Area (EAA): Water, Soil, Crop, and Environmental Management. University Press of Florida. Gainesville, Florida. 318 p.

15. Larry Fink and Peter Rawlik. 2000. The Everglades Mercury Problem. Chapter 7 *in* Everglades Consolidated Report. January 1, 2000. South Florida Water Management District. <http://www.sfwmd.gov>

16. Gleason, Patrick J. and Peter Stone. 1993. Age, Origin and Landscape Evolution of Everglades Peatland. pp. 149-197 *in* Everglades: The Ecosystem and Its Restoration. Davis, Steven M. and John C. Ogden (editors). St. Lucie Press. Delray Beach, Florida. 826 p.

17. Stephens, John C. and Lamar Johnson. 1951. Subsidence of Peat Soils in the Everglades Region of Florida. United States Department of Agriculture Soil Conservation Service. 47 p.

18. Stephens, John C. 1956. Subsidence of Organic Soils in the Florida Everglades. Soil Science Society Proceedings. pp. 77-80.

19. Light, Stephen S. and J. Walter Dineen. 1993. Water Control in the Everglades: A Historical Perspective. pp. 47-84 *in* Everglades: The Ecosystem and Its Restoration. Davis, Steven M. and John C. Ogden (editors). St. Lucie Press. Delray Beach, Florida. 826 p.

20. Davis, John H., Jr. 1943. The Peat Deposits of Florida: Their Occurrence, Development and Uses. Geological Bulletin No. 30. Florida Geological Survey. Tallahassee, Florida. 247 pp.

21. McCormick, Paul C., Susan Newman, ShiLi Miao, Ramesh Reddy, Dale Gawlik, Carl Fitz, Tom Fontaine and Darlene Marley. 1999. Ecological Needs of the Everglades. Chapter 3 in Everglades Consolidated Report. January 1, 1999. South Florida Water Management District. <http://www.sfwmd.gov>

22. South Florida Water Management District. 1999. Everglades Best Management Practices Program. Water Year 1999: May 1, 1998 through April 30, 1999. 5th Annual Report. <http://www.sfwmd.gov>

23. William W. Walker, Jr., and Robert H. Kadlec. 1996. A Model for Simulating Phosphorus Concentrations in Waters and Soils Downstream of Everglades Stormwater Treatment Areas. August 16, 1996 draft. 108 p.

Other References

South Florida Ecosystem Restoration Task Force. 1999. Maintaining the Momentum. Biennial Report to the U. S. Congress, Florida Legislature, Seminole Tribe of Florida, and Miccosukee Tribe of Indians of Florida. 24 p. <http://www.sfrestore.org/>

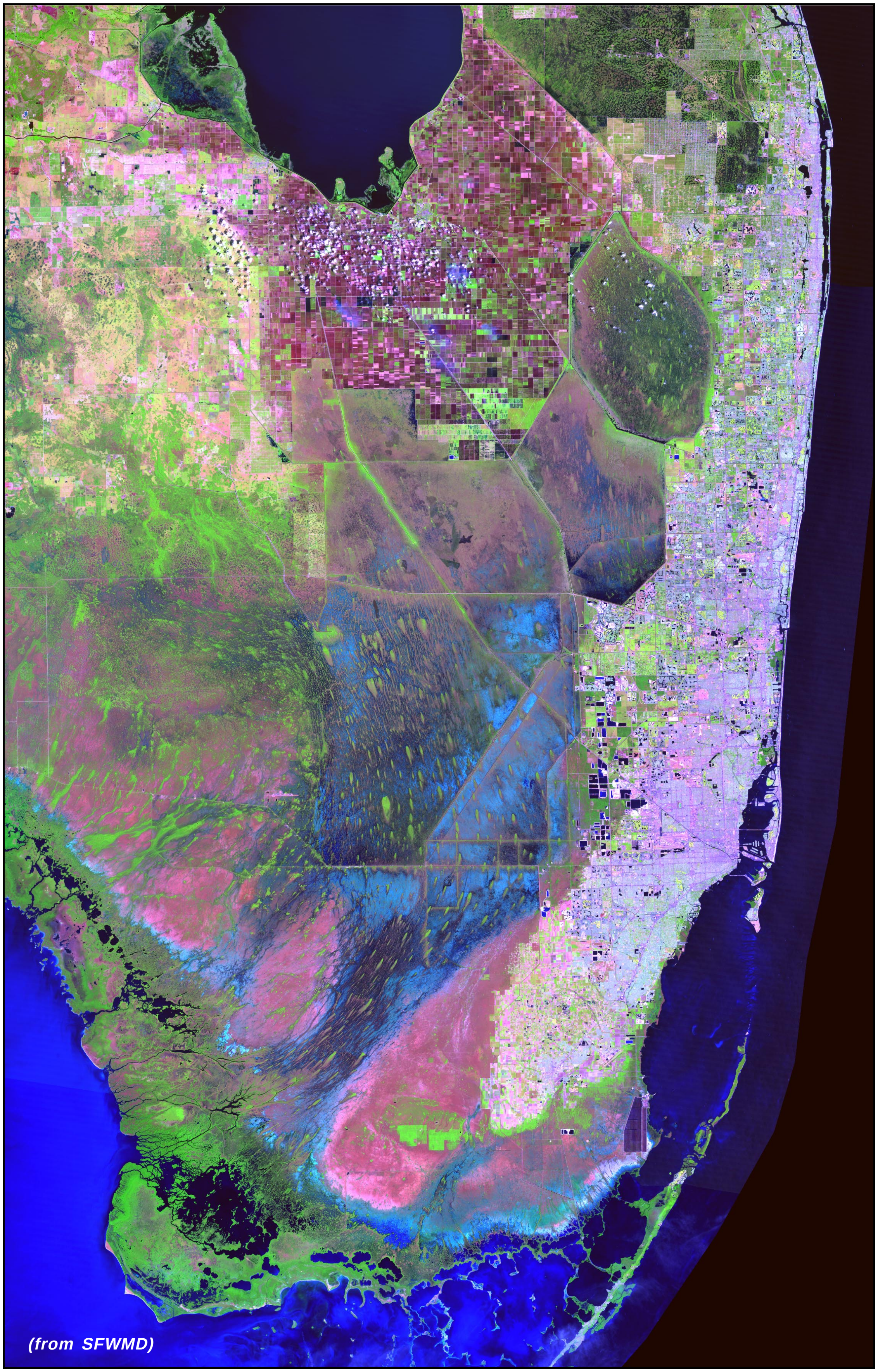
Stober, Q. J., R. D. Jones and D. J. Scheidt. 1995. Ultra Trace Level Mercury in the Everglades Ecosystem: A Multimedia Pilot Study. Water, Air and Soil Pollution vol. 80, p. 1269-1278.

Stober, Jerry, Daniel Scheidt, Ron Jones, Kent Thornton, Robert Ambrose and Danny France. 1996. South Florida Ecosystem Assessment: Monitoring for Ecosystem Restoration. Interim Report. EPA 904-R-96-008. USEPA Region 4 Science and Ecosystem Support Division and Office of Research and Development. Athens, Georgia. 26 p. <http://www.epa.gov/region4/sesd/sflea/sfleair.html>

Stober, Jerry, Daniel Scheidt, Ron Jones, Kent Thornton, Lisa Gandy, Don Stevens, Joel Trexler and Steve Rathbun. 1998. South Florida Ecosystem Assessment: Monitoring for Ecosystem Restoration. Final Technical Report - Phase I. EPA 904-R-98-002. USEPA Region 4 Science and Ecosystem Support Division and Office of Research and Development. Athens, Georgia. 285 p. plus appendices. <http://www.epa.gov/region4/sesd/reports/epa904r98002.html>

Photographic Acknowledgements

Table of contents water control structure and Figure 8: South Florida Water Management District; Figure 3: Everglades National Park; All other photographs: Daniel Scheidt.


(from SFWMD)