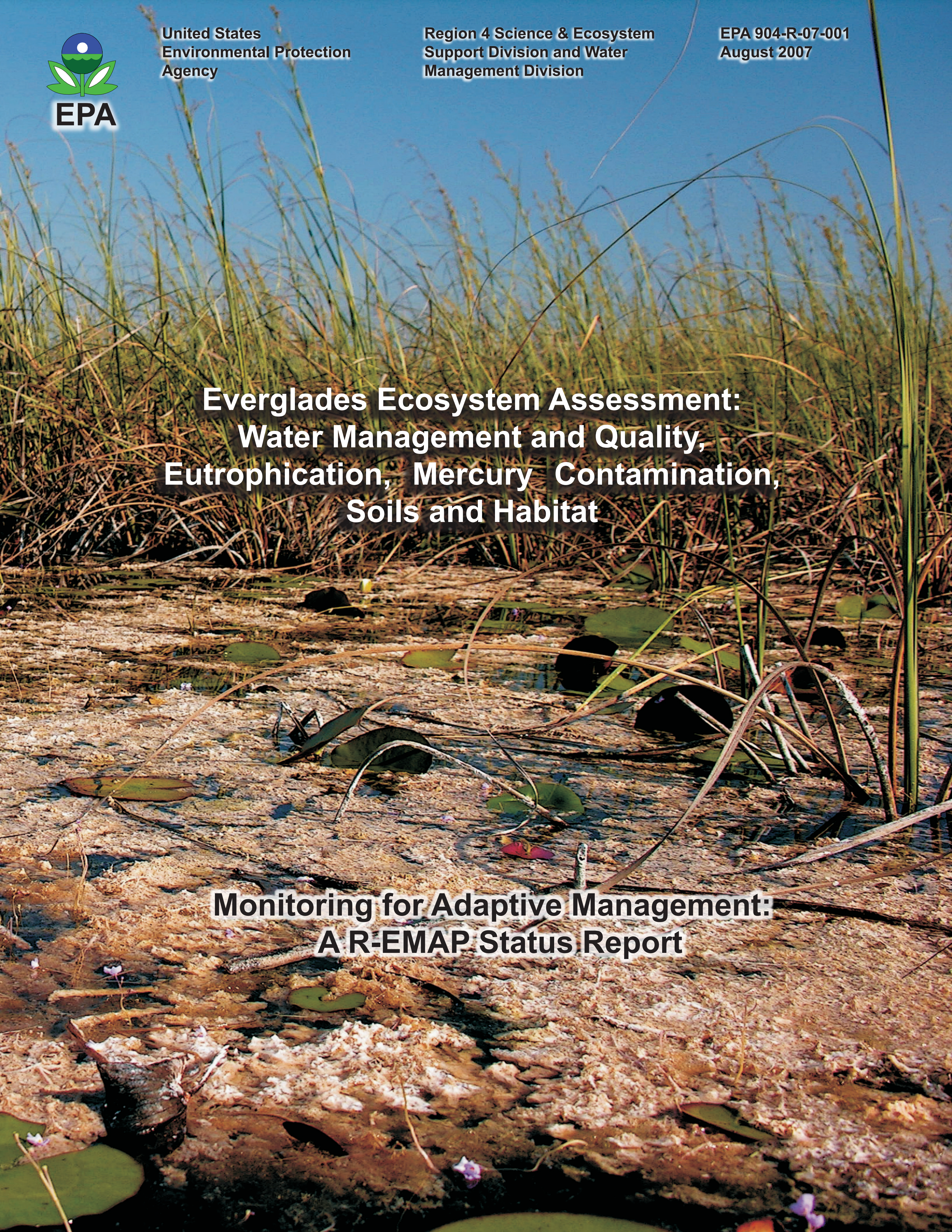

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Region 4 Science & Ecosystem
Support Division and Water
Management Division

EPA 904-R-07-001
August 2007

Everglades Ecosystem Assessment: Water Management and Quality, Eutrophication, Mercury Contamination, Soils and Habitat

Monitoring for Adaptive Management: A R-EMAP Status Report

The Everglades Ecosystem Assessment Program is being conducted by the United States Environmental Protection Agency Region 4 Science and Ecosystem Support Division, with the Region 4 Water Management Division cooperating. Many entities have contributed to this Program, including the National Park Service, United States Army Corps of Engineers, Florida Department of Environmental Protection, United States Fish and Wildlife Service, Florida International University, University of Georgia, Battelle Marine Sciences Laboratory, FTN Associates Incorporated, United States Geological Survey, South Florida Water Management District, and 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-07-001
August 2007

EVERGLADES ECOSYSTEM ASSESSMENT

Water Management and Quality,
Eutrophication,
Mercury Contamination,
Soils and Habitat

Monitoring for Adaptive Management

A R-EMAP Status Report

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

Everglades R-EMAP is a program of the United States Environmental Protection Agency's Region 4 Laboratory [the Science and Ecosystem Support Division (SESD) in Athens, Georgia], with the Region 4 Water Management Division (WMD) cooperating. Everglades R-EMAP is managed by Peter Kalla of SESD. Daniel Scheidt of WMD is the associate manager.

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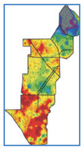


EXECUTIVE SUMMARY

The United States Environmental Protection Agency's Everglades Ecosystem Assessment Program is a long-term research, monitoring and assessment effort. Its goal is to provide critical, timely, scientific information needed for management decisions on the Everglades ecosystem and its restoration. Since 1993, three phases of marsh sampling and one phase of canal sampling have been conducted throughout the Everglades at over 1000 different locations. The Program is unique to South Florida in that it combines several key aspects of scientific study: a probability-based sampling design, which permits quantitative statements across space about the condition of the ecosystem; a multi-media aspect; and extensive spatial coverage.

This Program:

- contributes to documenting the effectiveness of phosphorus and mercury control efforts;
- contributes to the joint federal-state Comprehensive Everglades Restoration Plan (CERP) by quantifying 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: surface water, soil and sediment, vegetation, and fish;
- 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 stressors on the Everglades ecosystem, such as water management, soil loss, water quality degradation, habitat loss, and mercury contamination; and
- 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.

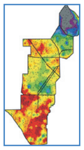
This report summarizes the results for the Program's 2005 Phase III biogeochemical sampling. This survey documented ecological condition for the 2,063-square-mile freshwater portion of the Everglades Protection Area. As with any assessment of the environment at large, the long-term goal of the Everglades R-EMAP Program is to first describe, then diagnose, and finally to predict the status of ecosystem conditions. The focus of this report is the description of the study area as a whole. Future publications will include examination of various parts of the system individually. Diagnosis and prediction will be the focus of future Program publications.

Key findings:

- ***Mercury contamination -- very slight changes in water:*** Statistical analyses of Program data indicate that there was a small decrease in the concentration of methylmercury in surface water in the wet season in 2005 as compared to the wet season in 1995. Conversely, there was a very slight increase in the concentration of total mercury in surface water in the wet season in 2005 as compared to 1995. This parameter had a median of 2.0 parts per trillion for the duration of the Program, well below the Everglades' water quality criterion of 12 parts per trillion. Unfortunately, attainment of the present criterion for surface water has not prevented bioaccumulation to unacceptable levels in prey fish.

- ***Mercury contamination -- declining in mosquitofish, but still elevated:*** The overall mercury concentration in mosquitofish, a key prey fish for Everglades gamefish and wading birds, dropped markedly from 1995-1996 to 1999 and from 1999 to 2005. This phenomenon was observed during the wet season and the dry season. However, during the 2005 wet season approximately 65% of the marsh exceeded 77 parts per billion, a concentration USEPA has recommended in trophic level 3 fish as being protective of top predators such as birds and mammals. The highest concentrations continue to be observed in Water Conservation Area (WCA) 3 and Everglades National Park (the Park), as was the case in 1995-1996. Over the entire study area fish mercury was highly correlated with mercury in forms of periphyton, but not with mercury in surface water.

- ***Mercury contamination -- bioaccumulation varies greatly over space:*** The bioaccumulation of mercury from the water column to mosquitofish varies spatially by a factor of approximately 10 throughout the Everglades. The highest concentrations of methylmercury and total mercury in surface water generally occur in WCA 2 and parts of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (the Refuge) - areas that do not have high mercury in mosquitofish. An inhibitory mechanism may explain the lack of bioaccumulation in these waters. Significant, negative correlation coefficients were found between bioaccumulation and forms of carbon and sulfur. The Program's sulfur, carbon, phosphorus and mercury data can be used to identify conditions associated with hot spots of mercury in biota, and to corroborate process studies designed to identify factors that enhance or inhibit mercury methylation and bioaccumulation. In addition, Program food web assessments will be available for most wet season sample sites, to shed additional light on bioaccumulation.



- ***Pronounced water quality gradients:*** There are clear spatial gradients in surface water phosphorus, sulfate, organic carbon, nitrogen, chloride and conductivity in the Everglades marsh. These gradients are due to the relative contribution of rainwater, stormwater and groundwater. The highest concentrations typically occur during the wet season in WCA 2, due to its proximity to the Everglades Agricultural Area and stormwater discharges. Concentrations progressively decrease downstream. Location, time of year, and water management practices are important factors that affect water quality.

- ***Canals are a conduit for pollutant transport:*** The canal system, constructed to provide flood control and water supply, is also 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 canals were eliminated or if they were operated to maximize surface water sheetflow and the diluting influence of rainfall and cleaner marsh water. Regardless, pollutants should be controlled at the source prior to discharge into the Everglades.

- ***Phosphorus enrichment:*** There was a slight decline in surface water phosphorus observed during the 2005 wet season sampling event as compared to 1995. During the November 2005 sampling event approximately 27% of the Everglades marsh had a surface water phosphorus concentration greater than 10 parts per billion. However, during 2005 soil phosphorus exceeded 500 milligrams per kilogram (mg/kg), Florida's definition of "impacted", in 24% of the Everglades, and it exceeded 400 mg/kg, CERP's restoration goal, in 49% of the Everglades. These proportions are higher than the 16% and 34%, respectively, observed in 1995-1996.

- ***Sulfate enrichment:*** About 57% of the Everglades marsh had a surface water sulfate concentration exceeding 1.0 parts per million (ppm), CERP's restoration goal. This contrasts with 66% observed in 1995. During November 2005 surface water sulfate was about 90 ppm in WCA2, well above marsh background of < 1.0 ppm. Interior portions of the Everglades distant from stormwater discharges from the Everglades Agricultural Area had concentrations < 1.0 ppm, although elevated concentrations were still found as far south as Shark Slough within the Park. The surface water sulfate concentration in the Everglades overall during the wet season showed a slight decrease from 1995-1996 to 2005.

- ***Soil loss in the public Everglades:*** The Program previously found that from 1946 to 1996, about one-half of the peat soil was lost from approximately 200,000 acres of the public Everglades that had been subjected to drier conditions. No overall change in soil depth was observed from 1996 to 2005. About 25% of the Everglades overall has 1.0 feet or less of soil, as does 53% of the Park. 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. The northern portion of WCA 3 must be rehydrated if further soil loss is to be prevented.

- ***Marsh habitat is a mosaic:*** Sawgrass marsh and wet prairie were the two dominant plant communities in the Everglades, representing 58% and 32% of the sites sampled in 2005. Water quantity and water quality must be managed properly to maintain these important habitats. Cattail was present, but not necessarily dominant, at 19% of the sites sampled in 2005, and was generally associated with elevated soil phosphorus or proximity to canals.

- ***Periphyton is conspicuous:*** Well-formed calcareous periphyton mats, a defining characteristic of the Everglades marsh complex where naturally hard water exists, were found at 63% 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 the Refuge and the southwest portion of WCA 3, were found to have good water quality and low soil phosphorus. The interior of the Refuge tended to have good water quality and the lowest phosphorus concentrations observed in peat soils. In contrast, northern WCA 3 had poorer water quality, thinner soil due to water management practices, elevated soil phosphorus, and extensive cattail encroachment. Water Conservation Area 2 had phosphorus enrichment and cattail encroachment, along with high sulfate, organic carbon, nitrogen, chloride and conductivity in surface water. Water depth at any given location varies with season and year.

- ***Environmental threats are interrelated:*** Ecological stressors such as water management, soil loss, water quality degradation, cattail expansion, and mercury contamination are often interrelated. Efforts to manage water quantity and pollutants such as phosphorus, mercury and sulfur should be integrated.

The Everglades R-EMAP Program has provided monitoring and assessment data for measuring ecosystem health and the effectiveness of Everglades restoration activities from the 1990s into the twenty-first century. As CERP restoration efforts and Everglades phosphorus and mercury control efforts proceed, this probability-based sampling can be repeated to document the condition of the Everglades and the effectiveness of these actions.

ABBREVIATIONS

cdf = cumulative distribution function
CI = confidence interval
cm = centimeter
cc = cubic centimeter
cfs = cubic feet per second
g = grams
ppb = parts per billion (ug/L)
ppm = parts per million (mg/L) or (mg/kg)
ppt = part per trillion (ng/L)
mg/kg = milligrams per kilogram (ppm)
mg/L = milligrams per liter (ppm)
ng/g = nanograms per gram (ppb)
ng/L = nanogram per liter (ppt)
ug/cc = micrograms per cubic centimeter
ug/g = micrograms per gram (ppm)
ug/kg = microgram per kilogram (ppb)
umhos/cm = micromhos per centimeter

AA = Alligator Alley (Interstate 75)
BAF = Bioaccumulation Factor
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
MeHg = Methylmercury
OFW = Outstanding Florida Water
Park = Everglades National Park
Refuge = Arthur R. Marshall Loxahatchee National Wildlife Refuge
R-EMAP = Regional Environmental Monitoring and Assessment Program
SFWMD = South Florida Water Management District
STA = Stormwater Treatment Area
TP = Total Phosphorus
USEPA = United States Environmental Protection Agency
WCA = Everglades Water Conservation Area
WCA 2A = Water Conservation Area 2A
WCA 3A = Water Conservation Area 3A
WCA 3B = Water Conservation Area 3B
WCA 3N = Water Conservation Area 3A north of Alligator Alley
WCA 3S = Water Conservation Areas 3A and 3B south of Alligator Alley
WY = Water Year

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US EPA REGION 4 EVERGLADES ECOSYSTEM ASSESSMENT PROGRAM

INTRODUCTION and PURPOSE

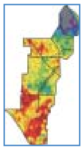
The United States Environmental Protection Agency (USEPA) Everglades Ecosystem Assessment Program (the "Program") is a unique, long-term, research, monitoring, and assessment effort. Its goal is to provide timely scientific information that is needed for decisions on the restoration and management of the Everglades ecosystem. Since 1993, one phase of canal sampling and three phases of marsh sampling have been conducted throughout the Everglades at over 1000 different sampling locations. The purpose of this report is to document conditions in the Everglades during 2005, the Program's third phase of marsh sampling. This Program is unique to South Florida in that it combines several key aspects of scientific study-

- probability-based sampling design, which permits quantitative statements across space about ecosystem condition;

- multi-media scope; and

- extensive spatial coverage.

Figure 1. Numerous environmental issues threaten the Everglades "River of Grass," such as water management, soil loss, water quality degradation, and habitat alteration. Two important features of Everglades habitat are shown here- sawgrass (background) and wet prairie-slough including well-developed periphyton (foreground).



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

The Everglades Ecosystem Assessment Program contributes to Everglades phosphorus and mercury control efforts and the Comprehensive Everglades Restoration Plan by:

- quantifying pre-restoration conditions in the marsh during 1995, as well as conditions subsequent to the initiation of restoration efforts later in the 1990s;

- assessing conditions in three physiographic regions: Everglades ridge and slough; marl prairie/rocky glades; and Big Cypress Swamp;

- providing information on four groups of Everglades restoration success indicators: water, soil and sediment, vegetation, and fish;

- providing a baseline against which future conditions can be compared, as well as change detection to gauge the effectiveness of restoration efforts;

- assessing the effects and relative potential risks of multiple environmental stressors on the Everglades ecosystem, such as water management, soil loss, water quality degradation and nutrient enrichment, habitat loss, and mercury contamination;

- providing unbiased estimates of ecosystem health with known levels of uncertainty;

- permitting spatial analyses and identifying associations that provide insight into relationships among environmental stressors and observed ecological responses; and

- providing data with multiple applications, such as 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; and developing water quality standards to protect fish and wildlife.

USEPA Region 4 and the Florida International University Southeast Environmental Research Center began this Program in 1993 to monitor the condition of the South Florida ecosystem. This Program has been carried out in cooperation with the United States Army Corps of Engineers, 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 the South Florida Water Management District.

This report, specified as a deliverable in the 2005 Phase III study plan, describes the ecological condition of the Everglades as a whole during the intensive 2005 marsh sampling effort. All reports and data for the Program 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.(1) 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 freely and slowly across the flat and level landscape. Rainfall during one season was still available during another. The enormous amount of water storage capacity and the slow flow made wetlands and coastal waters less vulnerable to South Florida's variable and often intense rainfall.(2)

Vastness. The large area provided a variety of wildlife habitats. Millions of acres of wetlands provided large feeding ranges and diverse habitat for wildlife. The vastness produced abundant aquatic life while facilitating recovery from hurricanes, fires, and other natural disturbances.(2)

Diverse mosaic of landscapes. The Everglades was a complex system of plant and animal life dictated in part by varied water regime - minimum, average, and maximum water depths, along with the duration of surface water inundation. This resulted in diverse, expansive areas of wet prairies, sawgrass marshes, cypress swamps, mangrove swamps, coastal lagoons and bays.(2)

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. Rainfall recharged groundwater and generated surface water, which interacted with the natural plant communities and soils. The slow flow of surface water across the landscape provided ample opportunity for cleansing by extensive wetlands. The sawgrass marshes and wet prairies of the Everglades developed under conditions of extremely low phosphorus concentration.

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 became 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

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

federal legislation. The Project's often conflicting purposes include flood control, water level control, water conservation, prevention of salt water intrusion, and preservation of fish and wildlife. The Project became one of the world's most extensive public water management systems, consisting of over 1,800 miles of levees and canals, 25 major pumping stations, and over 200 large and 2,000 smaller water control 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.(2) The Project has effectively provided flood control and water supply to facilitate urban and agricultural growth.

Today, 50% of historic Everglades wetlands have been drained. The Everglades ecosystem has been altered by extensive agricultural and urban development (Figures 4 to 8). South Florida's human population, which by 2000 was eight million, continues to increase, encroaching on the natural system and requiring increasing volumes of water. This human population is projected to increase to 15 million within a few decades.(2) (Figure 4).

The Everglades landscape changed dramatically during the twentieth century as drainage canals were dug to facilitate development. Most of the remaining Everglades are in the Everglades Protection Area (EPA): Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR or the Refuge), Everglades National Park (ENP or the Park), 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).(4) 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 vegetables are grown on the rich peat soils of drained sawgrass marshes. Another one-fourth of the historic Everglades has been drained and converted into urban areas along Florida's lower east coast.

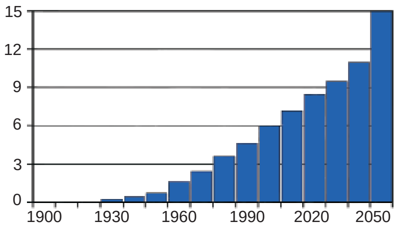


Figure 4. South Florida population in millions from 1900-2050 (projected). Flood control provided by the Central and Southern Florida Project has made urban expansion possible(2,3).

Figure 5. Urban expansion into drained Everglades wetlands within western 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 in western Dade County, 2005.

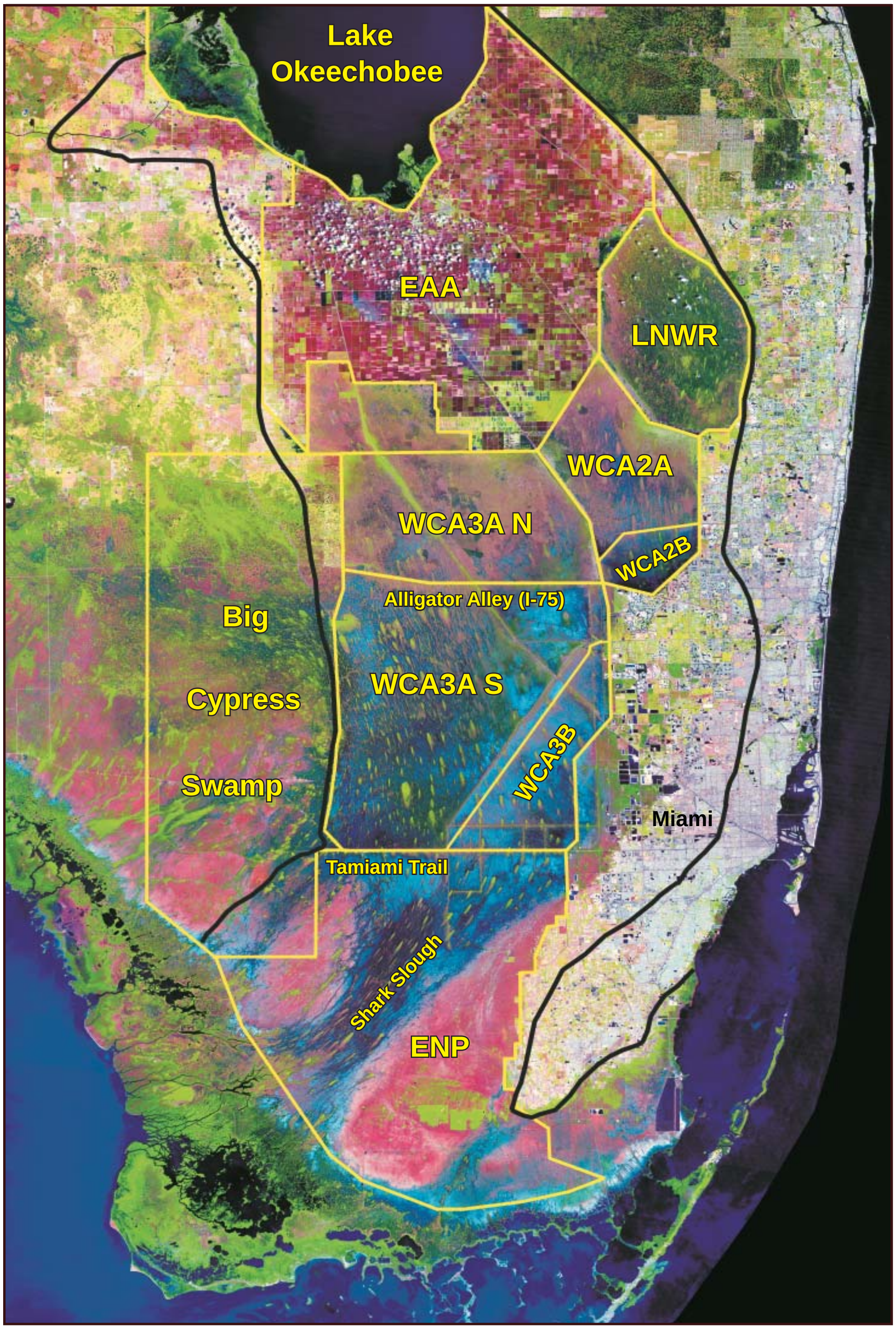


FIGURE 8. Satellite image of South Florida, circa 1995, with the areas sampled outlined in yellow: Everglades Agricultural Area (EAA); Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR); Everglades Water Conservation Area 2 (WCA 2); Everglades Water Conservation Area 3 north of Alligator Alley (WCA3A N); Everglades Water Conservation Area 3 south of Alligator Alley (WCA3A S); the eastern portion of Big Cypress National Preserve, and the freshwater portion of Everglades National Park (ENP). Light areas on the east are urban development. The black line approximates the extent of the historic (pre-1900) Everglades marsh. The Everglades watershed extends north of Lake Okeechobee.

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

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 protect and restore the Everglades ecosystem. These include: water management complexities; water supply conflicts; loss of water storage capacity; soil loss; water quality degradation and eutrophication; mercury contamination of game fish, wading birds, and Florida panthers; habitat alteration and loss; protection of endangered species; and introduction and spread of nuisance exotic species of plants and animals.

THE COMPREHENSIVE EVERGLADES RESTORATION PLAN (CERP)

The Central and Southern Florida Project has provided flood protection and water supply for urban and agricultural lands, as intended. However, the Project has simultaneously altered the Everglades, and indeed the entire south Florida ecosystem. Much of 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) decreased markedly during the twentieth century.(5) (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 have been irreversibly drained. Gone also are the water storage and water quality filtration functions that these wetlands once provided. 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 into the Everglades marsh are frequently too much or too little, and 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

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

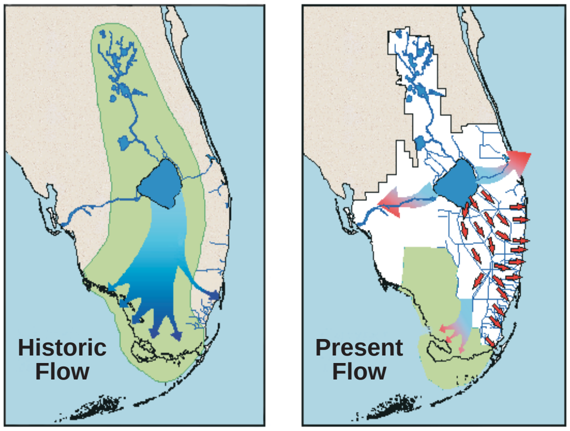


FIGURE 10. Historic (left) Everglades water flow patterns and present flow patterns (right)(adapted from 2, 6).

FIGURE 11. An extensive system of canals, levees, and water control structures has modified Everglades water conditions and provides a conduit for pollutant transport. The S-9 pump station (foreground) discharges untreated stormwater from an urban basin into the Everglades (background).

and can provide a conduit for pollutant transport from urban and agricultural areas (Figures 11 and 24). 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 improvements in water management (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 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, <http://www.evergladesplan.org/>), which was authorized by the United States Congress in the Water Resources Development Act of 2000.

The development of the Plan was led by the Army Corps of Engineers and the South Florida Water Management District and a team of more than 100 ecologists, hydrologists, engineers and other professionals from over 30 federal, state, tribal, and local agencies. The

Figure 12. The right quality, quantity, timing, and distribution of water are all critical to South Florida ecosystem protection and restoration(2).

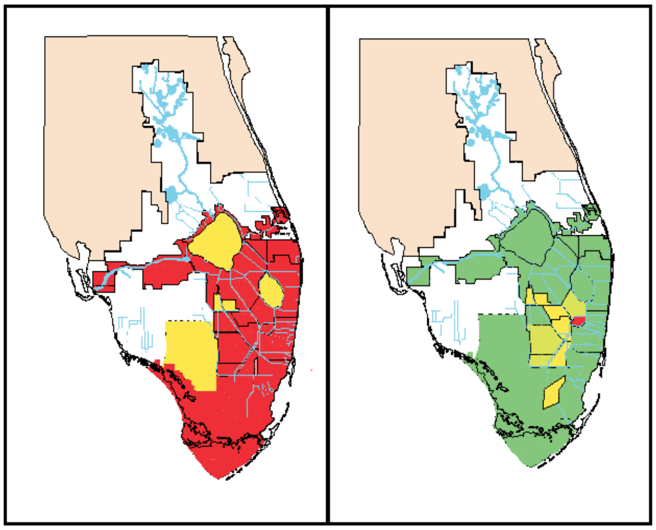
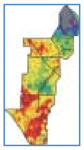


Figure 13. The anticipated effect of the Comprehensive Everglades Restoration Plan (CERP). Without the Plan (left) restoration targets will not be met (red). With the Plan fully implemented (right) restoration targets likely will be met (green). Yellow indicates uncertainty in meeting restoration targets(2).

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 over $11 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.(2,7) In 2004 the State of Florida announced an effort to speed up funding, design and construction of eight key CERP projects. This $2 billion effort, Acceler8, is focused at regaining some of the water storage capacity that was lost with wetland drainage by building water storage reservoirs, restoring water quality with treatment wetlands, and restoring surface water sheetflow and enhancing water management options.

Given the $11 billion investment in CERP, as well as phosphorus and mercury control efforts, monitoring and assessment of results are important. Monitoring data are needed to determine ecosystem condition, identify threats, and evaluate environmental restoration efforts. As CERP is being implemented in a phased manner, system-wide information is needed. Monitoring objectives include:



To evaluate restoration success, we must have reliable pre-restoration and post-restoration information on ecosystem condition.

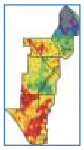
- Documenting status and trends;
- Determining baseline variability;
- Detecting responses to management actions;
- Improving the understanding of cause and effect relationships.

Accordingly, CERP has adopted an integrated monitoring and assessment plan that includes key performance measures as indicators of ecosystem health. Performance measures are indicators of conditions in components of the natural and human ecosystem that have been determined to be characteristic of a healthy, restored system. Achieving targets for a well-selected set of performance measures is expected to result in system-wide sustainable restoration. CERP performance measures are used to predict system-wide performance of alternative plans and to assess actual performance following implementation.(8)

There are 24 CERP performance measures for the greater Everglades focused on water conditions, water quality, plants and wildlife. The Everglades Ecosystem Assessment Program collects data that are relevant to over one-half of these performance measures.

Example Everglades Ecosystem Restoration Performance Measures.(8)

Water Management	Reinstate system-wide natural hydropatterns and sheet flow
Habitat Alteration	Increase spatial extent of habitat and wildlife corridors
Eutrophication	Water total phosphorus must be < 10 ppb and meet stricter OFW requirements for Park and Refuge. Soil TP < 500 mg/kg with 400 mg/kg goal. Surface water total nitrogen < or = 1994-2004 baseline.
Mercury Contamination	No statistically significant increase in levels of mercury in fish tissue
Sulfate Contamination	Surface water sulfate 1 mg/L or less
Conductivity	No more than 25% increase above background, maintain low conductivity in Refuge
Periphyton	Increase aerial coverage of habitats that reflect Natural Systems Model
Soil Loss	Restore natural soil formation processes and rates



USEPA REGION 4 EVERGLADES ECOSYSTEM ASSESSMENT PROGRAM

PROGRAM DESIGN

The attention and funding devoted to Everglades ecosystem restoration are unprecedented. Therefore, it is imperative that ecosystem health be assessed repeatedly and comprehensively in a cost-effective, quantitative manner. Such an assessment identifies resource restoration needs and 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 accurately determine the proportion of the current Everglades that is subject to various human impacts. This Program employs a scientifically rigorous method of accomplishing this requirement using probability-based sampling.

This Program uses a statistical, probability-based sampling strategy to select sites for sampling. This approach was initiated throughout the United States in the early 1990s by the United States Environmental Protection Agency and is referred to as R-EMAP (Regional Environmental Monitoring and Assessment Program). The Everglades R-EMAP effort began in 1993 in the freshwater portion of the Everglades. The Program area extends from Lake Okeechobee southward to the mangrove fringe on Florida Bay and from the ridge along the urbanized eastern coast westward into Big Cypress National Preserve (Figure 8). The distribution of the 199 canal sites and the 990 marsh sites sampled from 1993 to 2005 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.

This Program was the first in the Everglades to sample canals at randomly located probability-based locations away from water control structures. Canals were sampled in September 1993 and 1994, and May 1994 and 1995 (about 50 sites per sampling cycle).(9,10,11) Four marsh transects (44 stations) along phosphorus gradients downstream of water discharge structures were sampled during April 1994. Marshes were sampled at random locations in Phase I during the dry season (April 1995 and May 1996) and wet season (September 1995 and 1996), at about 120 sites per sampling cycle.(9) Big Cypress Swamp was also sampled during Phase I. During Phase II the freshwater Everglades marsh was sampled during May 1999 and September 1999 at another 119 sites per cycle.(12,13) Phase III was conducted in May 2005 and November 2005 at another 228 Everglades marsh sites. As of 2005 the Program has sampled 990 distinct marsh locations and 199 canal locations throughout the freshwater Everglades and Big Cypress.

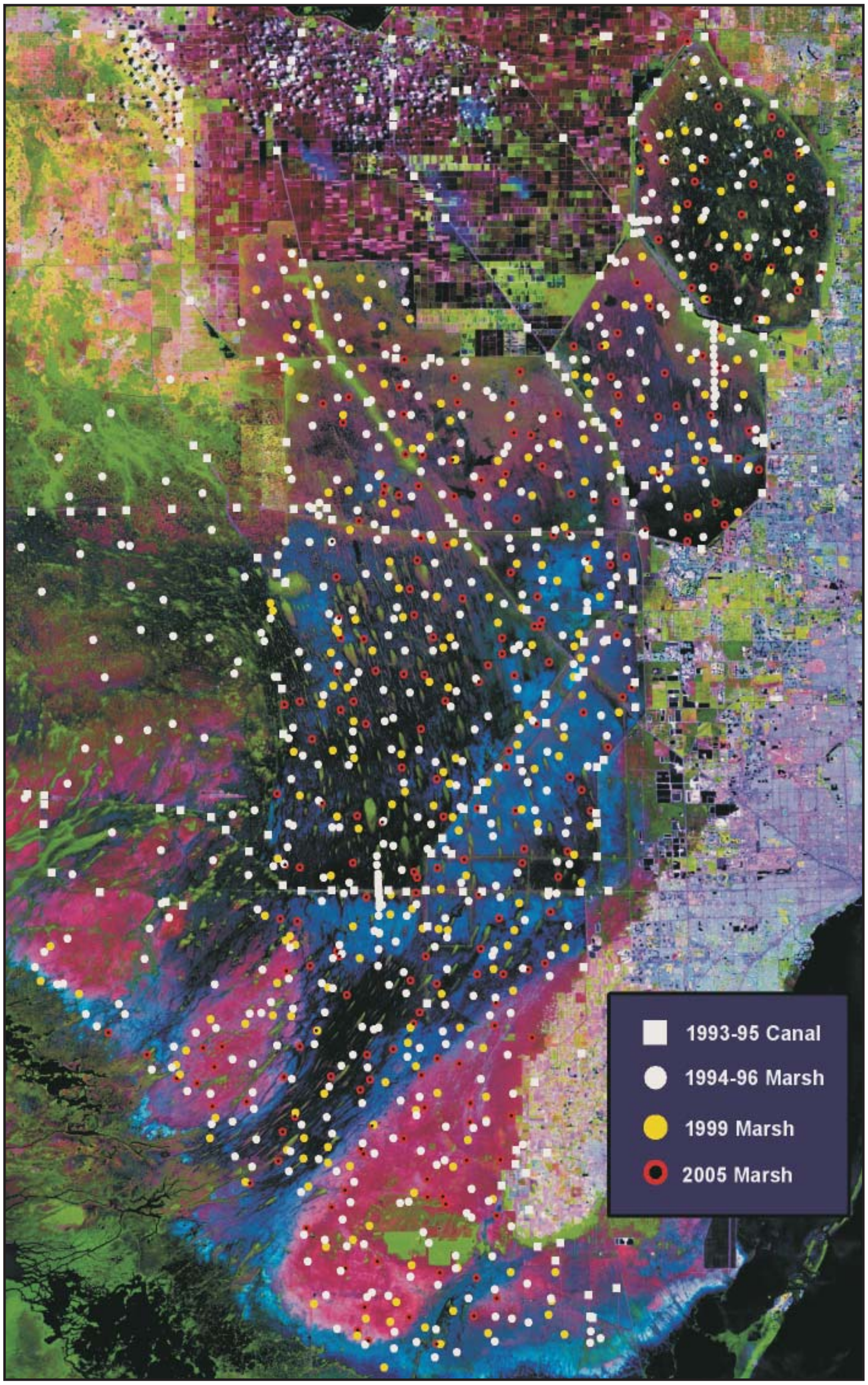


FIGURE 14. The 199 canal stations and 990 marsh stations sampled by the Program from 1993 to 2005.

During the 2005 Phase III sampling there were five Program components conducted at the 228 marsh stations (Table 1):

- classified vegetation maps were generated for square-kilometer plots centered on the station, based on aerial photography flown in 2000;
- aquatic food webs were assessed;
- periphyton community composition was determined;
- plant species frequency was recorded within quadrats along transects, along with exotic species;
- multi-media biogeochemical sampling was conducted to understand water quality and soil conditions. This report focuses on the biogeochemical sampling.

TABLE 1. Program history showing Phases, media and indicators.

Phase	**I**	**II**	**III**
Year(s)	**1995 & 1996**	**1999**	**2005**
Distinguishing characteristics:	Baseline data. Big Cypress included. Canals included 1993-95	Plant study added. Canals & Big Cypress omitted.	Change detection. Food web studies added. Invasive plant survey added.
Stations	480	238	228
Biogeochemical media			
Surface water	Yes	Yes	Yes
Floc	No	Yes	Yes
Porewater	No	Yes	Yes
Soil	Yes	Yes	Yes
Periphyton	Yes	Yes	Yes
Mosquitofish	Yes	Yes	Yes
Macrophytic plants			
Qualitative habitat categorization	Yes	Yes	Yes
Species frequency	No	Yes	Yes
Classified vegetation mapping	No	Yes	Yes
Invasive plant survey	No	No	Yes
Community ecology			
Periphyton assemblage	No	Yes	Yes
Mosquitofish food habits	No	Yes	No
Macroinvertebrate assemblage	No	No	Yes
Isotope studies	No	No	Yes

Because the Program involves sampling remote locations throughout an extensive area, each biogeochemical marsh sampling event is performed by two or three teams using helicopters equipped with floats. It takes about 9 days for the field teams to simultaneously sample about 120 sites total while moving upstream from south to north.

The six media sampled at each site included surface water (Figure 15), marsh soil (Figure 36), periphytonous algae and diatoms (Figures 1, 54 and 56), and prey fish (Figure 15). Pore water (interstitial water contained within wetland soil) and floc (flocculent material found at the surface water-soil interface, Figure 15) were sampled beginning in 1999. All of these media are important for elucidating the cycling of nutrients and mercury. The Program does not have a minimum surface water sampling depth due to the importance of shallow conditions in understanding cycling processes for mercury and nutrients.

Figure 15. Biogeochemical sampling included surface water (top left), floc and soil (top right), and mosquitofish (bottom). The surface water sampling apparatus (top left) and soil coring device (top right) were designed and constructed for the Program.

DATA QUALITY ASSURANCE

The biogeochemical portion of this Program comprises a multi-media effort in which six marsh media (Table 1) are sampled concurrently and consistently throughout the entirety of the freshwater Everglades. During the 2005 sampling, in-situ physico-chemical data were documented at 228 sampling stations. Eight analytical labs were contracted to perform the necessary variety and volume of nutrient, anion, mercury, physical and biochemical analyses for samples collected at these stations. There were about 60 laboratory test methods performed for the various analytes among the media sampled (Appendix I). Analytes included total mercury and methylmercury, and forms of phosphorus, nitrogen, sulfur, carbon, along with enzymes and physical parameters. The Program defined data quality objectives to assure that data would meet Program goals. An independently reviewed Quality Assurance Program Plan was developed in accordance with USEPA protocol.(14, 125) Data quality was an integral part of the planning and execution of the 2005 effort, including the selection of qualified analytical laboratories and the refinement of field sampling methods.

CERP has recognized the importance of data quality, resulting in the adoption of Quality System Requirements. In Everglades R-EMAP, quality assurance is treated as an essential, co-equal component of the work, from earliest efforts in Program planning, during field sampling events and subsequent laboratory work, and through to final data review and validation. One goal of this Program is to produce data of known and documented quality that satisfy pre-defined uses and requirements. The Program has an independent quality assurance officer who oversees all aspects of data quality. Data that potentially could be used for regulatory purposes, such as phosphorus, sulfur, and mercury, were obtained from analytical laboratories that are accredited by the National Environmental Laboratory Accreditation Program.

During May 2005, 109 stations were sampled and about 1970 sample containers were generated. In November 2005, 119 stations were sampled, generating about 3110 sample containers (Figure 17). During 2005 about 25,000 sample results were produced, 100% of which were subjected to an independent quality assurance review. Only 2 individual analytical results were rejected as not meeting Program data quality objectives. About 10% of the Program budget was invested in data quality assurance.

DATA USES

This Program permits a holistic view of indicators of ecological condition throughout the freshwater canal and marsh system. An indicator is a measurable characteristic of the

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

FIGURE 16. The probability-based sampling design ensures that all habitats, such as dense cattail, are sampled.

FIGURE 17. Surface water and pore water samples in the chain of custody lab at the end of a day's sampling. Samples were distributed to eight analytical laboratories for determination of mercury, nutrient, and ionic content.

environment, abiotic or biotic, that can provide information on the condition of ecological resources. The Program's large-scale perspective is critical to understanding the impacts of different factors (such as phosphorus, mercury and sulfur 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 misleading perspective. This Program is unique to South Florida: its extensive spatial coverage and sampling intensity are unprecedented, as is its multi-media approach. It is the only Program sampling throughout the Everglades with a probability-based design which permits quantitative statements about ecosystem condition.

A key advantage of this Program's probability-based statistical approach is that it allows one to estimate across space, with known confidence and without bias, the current status and extent of indicators for the condition of ecological resources.(15,16) 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 USEPA has applied it to lakes, rivers, streams, wetlands, estuaries, forests, arid ecosystems and agro-ecosystems throughout the United States.(17, 18)

During planning for the 2005 phase of the Program, efforts were made to assure that data collected would meet critical information needs of managers and scientists involved with Everglades protection and restoration. Program managers met with Florida and Federal managers and scientists involved with CERP and Everglades phosphorus and mercury control efforts. Entities represented included Everglades National Park, Arthur R. Marshall Loxahatchee National Wildlife Refuge, the U. S. Army Corps of Engineers, the South Florida Water Management District and the Florida Department of Environmental Protection. In addition, the 2005 Program study plan was subjected to an external scientific peer review by each of these agencies and by the USEPA R-EMAP national program office.

Parameters measured for the Program at each site can be used to answer questions about 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 and sawgrass marsh distribution, presence of exotic plant species)
- Mercury contamination (e.g., mercury in water, soil, algae, and prey fish)

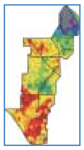
Specific questions related to Everglades restoration goals that this Program answers include:

- How much of the marsh or canal system has a total phosphorus concentration greater than 50 parts per billion (ppb) in surface water, Florida's initial phosphorus control goal, or 10 ppb, the water quality criterion for the Everglades? Is it changing over time?
- How much of the marsh has surface water sulfate concentrations that exceed 1 part per million (ppm), the CERP performance measure for Everglades marsh restoration?
- How much of the marsh is dominated by sawgrass? Wet prairie? In what percent of the Everglades is cattail present?
- How much of the marsh has a soil total phosphorus concentration that exceeds 500 milligrams per kilogram, Florida's definition of "impacted" for Everglades soils, or 400 milligrams per kilogram, the CERP restoration target?
- How much of the marsh still has the natural oligotrophic periphyton community?
- How much of the marsh area is dry, and where?
- How much of the marsh soil has been lost due to subsidence? Is the rate of this loss changing over time?
- How much of the marsh has prey fish with mercury levels that exceed 100 ppb, a level that presents an unacceptable increased risk to top predators such as wading birds?
- What water quality conditions are associated with marsh zones of high mercury bioaccumulation?

The South Florida Ecosystem Assessment Program provides such information system-wide for the freshwater Everglades marsh. Data from this Program have been used by scientists and managers from over 20 agencies or private interests for many purposes, such as:

- Assessing drought-related ecological risk in the Everglades(19)
- Determining which portions of the Everglades are phosphorus-impacted according to Florida's Everglades phosphorus criterion rule(20,21), and determining which portions are phosphorus-impaired as defined by the Clean Water Act for the Total Maximum Daily Load (TMDL) program
- Understanding morphological response of macrophyte species to phosphorus(22)
- Understanding sulfur cycling, the distribution of surface water sulfate and the penetration of water with high sulfate content into the Everglades marsh(23,24)
- Understanding the penetration of water with high ionic content into the marsh in the Refuge and its potential impacts on periphyton communities(25)
- Documenting reference conditions and developing CERP performance measures for soil phosphorus and surface water conductivity and sulfate(8)
- Documenting mercury conditions in water and biota and calculating the ecological risk to Everglades top predators such as birds(24,26,27,28)
- Using nitrogen, carbon and sulfur isotope data to understand spatial variations in aquatic food webs(29)

The long-term goal of the R-EMAP Program is to first *describe* the environmental status of the ecosystem, then to *diagnose* the probable causes of observed impairments, and finally to *predict* ecological responses of the system to management actions. Description is accomplished by the measurements and interpretations presented here; diagnosis is furthered by multivariate statistics that relate the measurements to each other; and prediction is done by using those relationships to project present-day actions into future status. This report focuses on the first goal and initiates the second. The third goal is the subject of forthcoming journal publications. This report describes ecosystem status and change based on two decades of intermittent sampling of the marsh. Conclusions about status are based on analyses of the system as a whole. Findings about change should not be construed as classical trend analysis, since the frequency of sampling is low. Experience in the EMAP Program nationwide suggests that this limitation applies more to surface water, which can be affected by weather events, than to soil or biota, which change less rapidly from time to time.(126, 127, 128) These more conservative media permit change detection over the long term. Results about water constituents will be placed in context as they are presented.



SAMPLING DESIGN AND DATA ANALYSIS

Probability Samples

In a probability sample, every unit of the population has a known chance of being selected and the sample is drawn at random. In 2005 a stratified random design was used, wherein sampling stations were located within each major sub-area separately, to assure a sufficient number of stations in the smaller sub-areas (the Refuge and WCA 2, as compared to WCA 3 or the Park). Sufficiency was judged by the resulting adequacy of coverage, important for providing information to meet certain data quality objectives of the survey. Every location in each major sub-area had an equal chance of being sampled. The sampling design was not biased to favor one marsh type over another (e.g., avoiding tall, dense sawgrass because it is an unpleasant habitat in which to work, sampling only next to a road because it is easier, or selecting a particular location because it looks good or bad). Two major advantages are obtained from probabilistic designs: the results represent the spatial distributions of the parameters that were measured; and the results can be used to estimate, with known confidence, the proportion of the area that was in any given condition. Estimates for the entire study area were made possible by accounting for unequal sample size among sub-areas. Estimates can also be made by sub-area, but were not computed for this report.

Kriging

Kriging is a geostatistical method of generating contour maps from irregularly spaced data. Since random sampling stations are spaced in such a manner, kriging is the natural choice for spatial depiction of R-EMAP results. The contours are isopleths, lines of equal estimated value of any measurement. Kriging algorithms interpolate between actual data points, producing a grid of estimated values from which the contours are drawn. The krigs in this report are true to the data – i.e., the data value at each sampling station matches the color of the contour interval at that point. For this report krigs were made by estimating a value for each node (intersection of lines) of the grid using the linear variogram model (no nugget effect). A variogram is an expression of how quickly the actual values change over space, on average, while taking into account the overall variability of the data set. The underlying assumption of variograms is that, on average, values from points closer together are more similar than those from points farther apart. Variograms are a function of direction, to account for directionality of physical processes that underlay the data. In the case of biogeochemistry in the Everglades, the process is often water flow.

The krigs in the report are only included to provide visual information for parameters with clear spatial gradients. Conclusions in the report about extent of impacts and changes over time are not drawn from the krigs, but rather from various statistical tests.

Particularly during the dry season, there are physical barriers to sheetflow in the Everglades, such as levees and roads. However, during the height of the wet season (generally the time of wet-season R-EMAP sampling), the sub-areas of the Everglades are hydrologically connected by surface water flowing freely through numerous structures. This concept is suggested by Figures 24 and 40 in the report. During November 2005 all structures were open and had been for some time. For example, L-67A/C/x was a conduit from WCA 3 into the Park. Connections between some compartments are so extensive that they are treated in some hydrological models as one unit. For example, the South Florida Water Management Model, a model used to project water conditions throughout the Everglades, disregards the presence of Alligator Alley. While wet season connectivity is neither perfect nor complete, isolation of the sub-areas is neither perfect nor complete as well. The real truth lies somewhere in between, and is dependent upon proximity to water control structures. Dry-season surface water conditions are different, but only to a greater degree, with porewater conditions probably more so. An additional consideration involves surface water total mercury. This constituent is driven more by atmospheric deposition than by water flow, largely negating the influence of physical barriers. The preceding considerations are the basis for kriging the entire study area as one unit, following the approach used in previous reports and by other investigators.

In validating krigs of large, complex systems like the Everglades, it is useful to look for places where the algorithm appears to have produced results that are a long-distance extrapolation across a barrier, rather than interpolation between connected points. Based on this logic, some krigs were generated by sub-area for this report. There are others that were affected somewhat by extrapolation, especially in areas near levees where there were few sampling points, and most notably where extrapolation was up-gradient, as is the case where a point in WCA 2 affected the contours in the Refuge. However, in these cases the effects are minimal and very localized.

Pearson correlation coefficient

Correlation is a statistical tool for determining the strength of interdependence, or association, between two variables. The Pearson r coefficient (Appendix III) is an indicator of the linear proportionality of associated variables. If two variables are perfectly correlated in a linear fashion, a change in one variable is always accompanied by a change of equal magnitude in the other variable. The coefficient can be any number between – 1 and + 1. Positive values of r result from direct correlation, where one variable increases as the other increases, whereas a negative r means inverse correlation (one decreasing as the other increases). Coefficients near 0 indicate weak correlation. In the case of Everglades R-EMAP, measurements vary over space (station to station) as well as time. Data from the same cycle can be analyzed for correlation, because the measurements (or environmental samples preserved for subsequent chemical analysis) were obtained from the same place at the same time. In addition to coefficients themselves, the statistical significance of the coefficients is reported. The significance (p) of a statistic is a measure of the reliability of the sample data set as a representative of the entire population of possible data points. The value of p is the chance that the true coefficient in the population is 0, or in other words, that instead of a strong or even a weak correlation, there is none at all. For this document, correlation coefficients are reported in the text only if $p<0.001$: a level at which there is less than a 1 in 1000 chance that the two variables are not associated.

CDFs and area estimates of Everglades contamination

One way to portray survey statistics is to plot the cumulative distribution function (cdf) of the data (Figure 31). All estimates of area by cdf curve in this report were generated from the original data, using algorithms in the R statistical package developed in part by EMAP program statisticians at the USEPA Office of Research and Development Laboratory in Corvallis, Oregon. Krigs were not used to estimate cdf curves. A cdf curve can be used to estimate the proportion of the Everglades where a given analyte was found at a concentration above or below any value of interest. This is a major strength of R-EMAP's probability-based sample design. In this report the cdf curve is shown in bold. By reading up to the cdf from any concentration of interest on the x-axis, and then across from the curve to the y-axis, one can read the corresponding proportion directly on that axis. Bounding the cdf are two lines representing the upper and lower 95% confidence limits, respectively, calculated using the Horvitz-Thompson estimator. These limits show the confidence interval (CI) around the area estimate. This interval, expressed as percentage points above and below the estimate, indicates the precision of the estimate: narrower intervals represent more precise estimates. Estimates tend to become more precise as the number of samples increases. At the 95% confidence level, there is a 1 in 20 chance that the true value for the study area was outside the range defined by the confidence interval. The CI for any estimate is read in the same manner as the estimate itself. For example, in Figure 31, 57.3 ± 6.0% of the 2063 square mile Everglades region sampled had a surface water sulfate concentration exceeding the CERP restoration goal of 1.0 mg/L. A typical R-EMAP data quality objective is to produce 95% CIs that are no larger than ± 10%. Previous experience in the national EMAP program and in the earlier phases of Everglades R-EMAP showed that approximately 125 stations was a sufficient sample size to meet this objective.

STATISTICAL TESTING FOR DIFFERENCES ACROSS SAMPLING YEARS

Any pair of R-EMAP data sets, represented by their respective cdf curves, can be tested statistically to indicate a difference, or lack thereof, between them. The test statistics for cdf curves used in this report (Wald, mean Eigenvalue, and Satterthwaite) express the likelihood of differences or similarities between values obtained at neighboring sample sites. These tests allow for statistical inference to the sampled population, or study area. In other words, if curves from different time periods or sampling phases are different, the underlying condition of the resource can be said to have changed. Statements about change are made with a specified degree of confidence, typically no more than a 1 in 20 chance of being wrong. This chance is expressed as a probability ($p < 0.05$ in the typical case). The source of such an error is that the supposed difference is due merely to random differences between the samples, instead of being a real change in the resource caused by some natural phenomenon or human activity. Only a random sample spread out over an entire study area (R-EMAP) can be used to draw conclusions about the whole area.

Z-TEST

To corroborate the results of the cdf tests, and to answer the different question, “Are the means (averages) of two R-EMAP data sets different enough to infer that there has been an increase or decrease of the mean over time in the study area?”, another statistical test was employed. It is a version of the commonly used test (t-test) for a difference between the means of two populations represented by large, independent samples having unequal size and variability. The version used for survey (probability) samples, the z-test, takes into account the slightly unequal density of stations from sub-area to sub-area in the stratified design of the 2005 survey.

BOX AND WHISKER PLOTS

A box-and-whisker plot (Figure 38) is another way to portray survey statistics for measured variables. This type of graphic depicts the distribution, or general shape, of the data for any variable of interest. The large box shows the interquartile range, between the 25th and 75th percentiles, which contains the middle half of all the data values. The whiskers include values outside the interquartile range that are not considered outliers (larger or smaller than the percentiles by at least 1.5 times the interquartile range) or extremes (2 times the range). Half of all the values are greater than the median, and half are less.

WATER MANAGEMENT

FIGURE 18. Rainfall at an Everglades wet prairie-slough in WCA 3 during the May 2005 field sampling. Surface water depth is about 2 feet.

A dominant force defining the historic Everglades was water: highly seasonal rainfall; slow, unimpeded, sheet-like surface 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 over tens of miles, produced a variety of water depths and hydroperiods (duration of surface water inundation). Water helped create the ridges and sloughs of the landscape. It also affects the foraging success of nesting wading birds. Because changes in surface water depth, distribution and hydroperiod caused many of the harmful changes to the historic Everglades, water is key to ecosystem preservation and restoration. Rainfall and the general patterns of water depth observed from 1995 to 2005 are described in this section.

Rainfall is highly seasonal, with about 80% falling during the May to October wet season (Figures 18 and 19). Rainfall during the 1995-1996, 1999, and 2005 sampling periods varied. Discharge through public water pumping stations is also highly seasonal. For example, at S-8, a pumping station that provides flood control for part of the Everglades Agricultural Area, monthly discharge varies from zero during the winter dry season to 68,000 cubic feet per second (about 136,000 acre-feet) in response to summer and fall rain events (Figure 20).

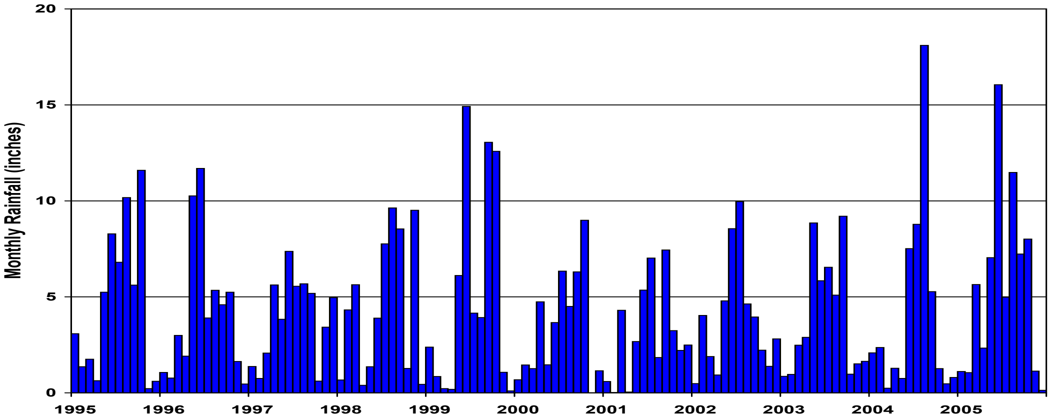


FIGURE 19. Monthly rainfall (inches) from 1995 to 2005 at S-8, a pumping station that provides flood control for part of the EAA by discharging water southward into the Everglades.

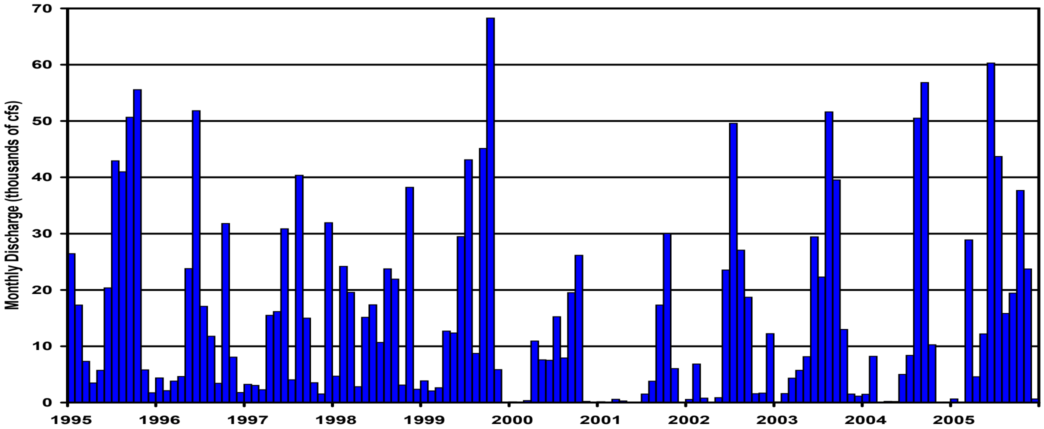


FIGURE 20. Monthly discharge at S-8. Discharge varies from zero to several thousand cubic feet per second in response to rain events.

Marsh water depths vary greatly with season, year and location in response to rainfall and discharges from water control structures (Figures 18, 21 to 23). During all four wet season sampling events the entire marsh was inundated. Water depths are deepest immediately upstream of levees that impede the natural flow of water, such as in the Refuge and WCA 2 and WCA 3A (Figure 23). All of these long-hydroperiod areas remained wet during the study period, and unnaturally deep water (depth of over five feet) was observed within eastern WCA 3A where the L-67 levee prevents sheetflow to the south. Short-hydroperiod portions of the marsh are subjected to annual periods of drying.

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

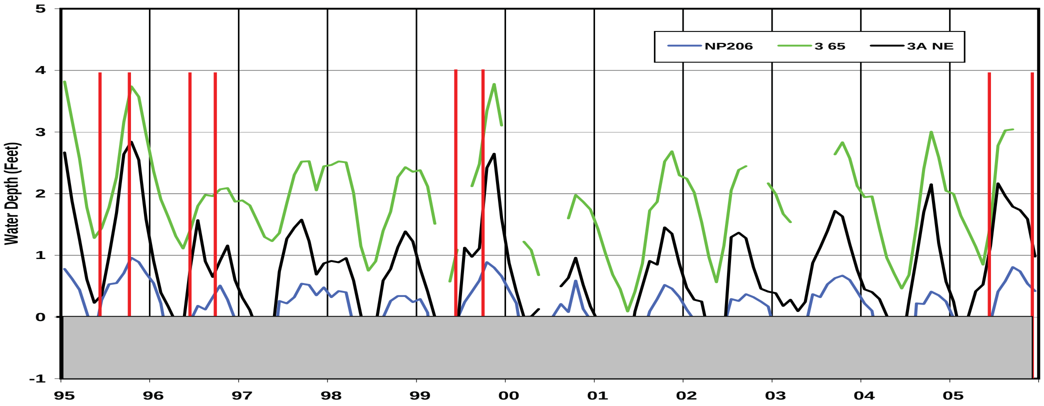


Figure 22. Surface water depth encountered in the Everglades marsh from 1995 to 2005 at three locations. The eight Program biogeochemical sampling events are indicated by vertical red lines.

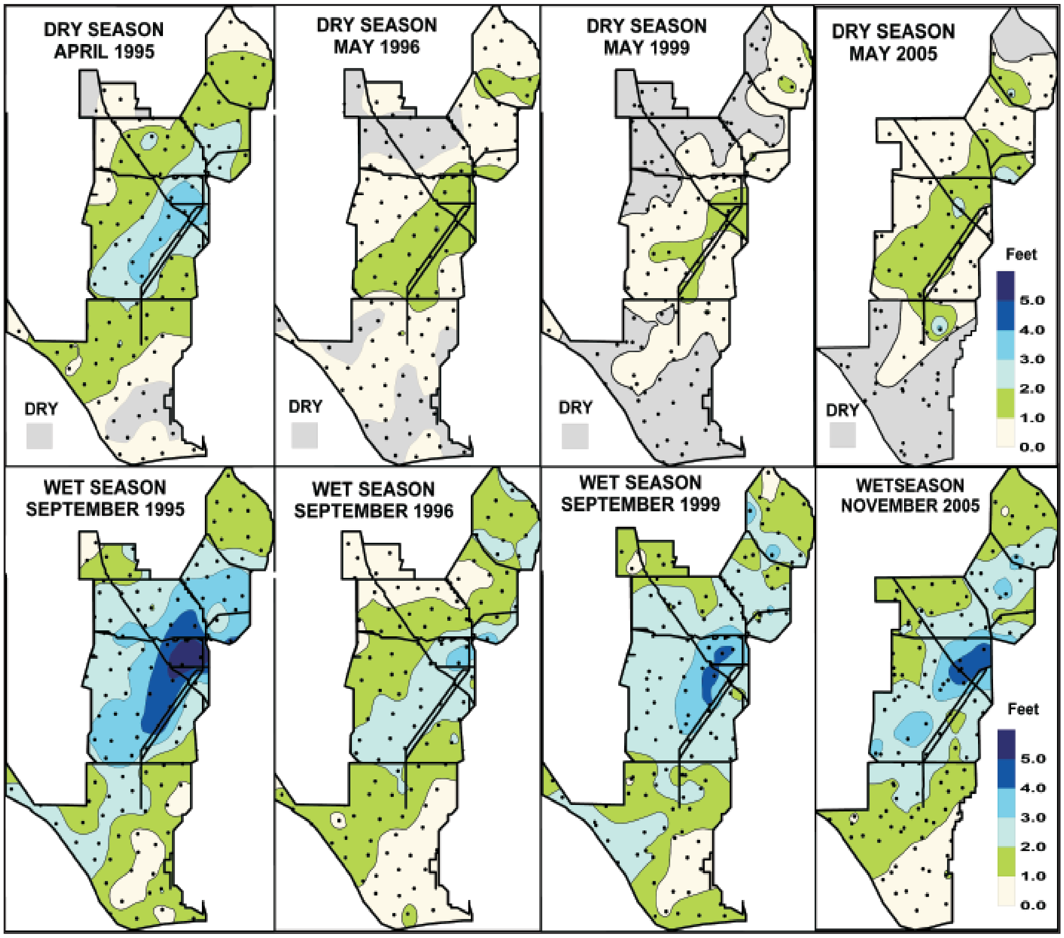


Figure 23. Krigs of surface water depth encountered in the Everglades marsh during the eight Program biogeochemical sampling events. Kriging is a statistical technique for drawing contour maps.

The subtropical Everglades ecosystem is subjected to varying climatic conditions, including hurricanes and drought. R-EMAP marsh sampling events occurred from 1995 to 2005, a period that encompassed very dry conditions as well as several hurricanes. Water was deeper than average in the Everglades during September 2005 and R-EMAP sampling was delayed. On October 23, 2005 the eye of hurricane Wilma passed over the southern edge of the EAA. Wilma inflicted wind damage but moved quickly, providing only 2 inches of rainfall on the Everglades.(132) R-EMAP sampling began 16 days later on November 8.

R-EMAP sampling events have occurred under a variety of water conditions (Figures 22-23). During the dry season sampling events the dry proportion of the marsh was 7% in April 1995, 16% in May 1996, 54% in May 1999 and 30% in May 2005. These estimates of area are not based on krigs but rather are calculated from the raw water depth measurements using statistical algorithms. The deepest conditions were encountered during 1995. This report largely focuses on the wet season for drawing conclusions about changes over space and time, for several reasons: The entire study area was represented; sample sizes were larger; and there were minimal effects of differential evapo-concentration of analytes in water. Program data have been used to validate predictive models of hydroperiod. The extent and distribution of dried areas have repercussions for Everglades ecology.(19,30)

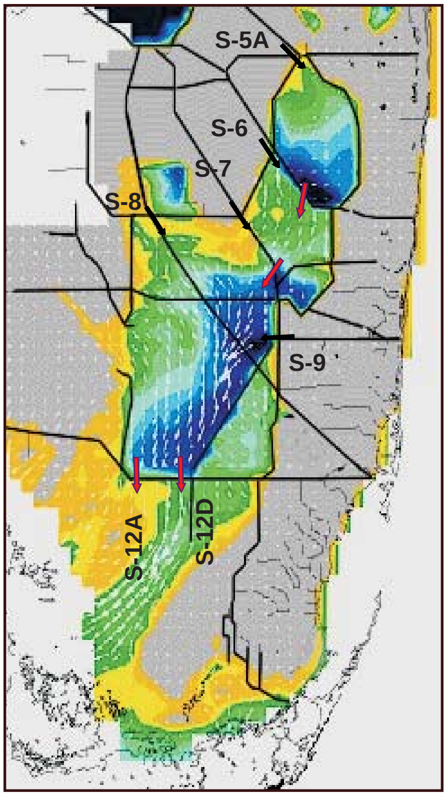


Figure 24. Surface water flow vectors during the wet season. Black arrows indicate major water control structures that pump stormwater into the Everglades. Red arrows indicate major gated spillways that move water within the Everglades (adapted from SFWMD). Blue areas indicate deeper water due to the ponding of surface water at levees.

	1995	*1996*	*1999*	*2005*
S-5A	146.6	25.4	54.1	50.4
S-6	173.4	38.4	74.2	77.6
S-7	106.8	11.2	60.4	98.9
S-8	208.1	30.2	107.8	116.8
S-9	77.6	44.8	69.9	29.1
Total	712.5	150.0	366.4	372.8

Table 2. Surface water discharge at the five major pumps discharging stormwater into the EPA. Flows are in cumulative thousands of acre-feet for the 60 days prior to each R-EMAP wet season sampling event.

WATER QUALITY

CONDUCTIVITY

The conductivity, or specific conductance, of a solution is a measure of its ability to carry an electrical current. It varies with the number and types of ions in solution. Pure water has a very low electrical conductance of a few hundredths of a micromho per centimeter (umho/cm).(31) Conductivity is very useful for understanding the source of water and its flow path. The water in the interior marsh of the Refuge is soft, slightly acidic, and strongly influenced by rainfall. The limestone (calcium carbonate) substrate underlying the Refuge is overlain by several feet of peat so surface water is not in contact with the limestone. In contrast, the rest of the Everglades marsh has hard water with a neutral pH. In the shorter hydroperiod portions of the Park there is little soil, so surface water is subject to greater influence by the limestone substrate. Conductivity of water is closely related to its hardness, because calcium, the major contributor to hardness in the Everglades, also aids in conductance. Conductivity is of ecological interest in that it is a determinant of periphyton community composition in the Everglades. Periphyton communities in the Refuge are dominated by desmid and diatom species, while the extensive periphyton mats (Figures 1 and 56) in hard water portions of the Everglades are dominated by calcium-precipitating cyanobacteria with a high calcium carbonate content.(25)

The Everglades has pronounced conductivity gradients due to the relative influence of rainwater, groundwater, and stormwater inflows (Figure 25). Pronounced spatial and seasonal patterns are evident. Precipitation in the Everglades has very low ionic content, with median annual specific conductivity for 2005 of about 18 umhos/cm.(32) In contrast, the conductivity of water discharged from the EAA during the wet season is about 50 times higher (1,000 umhos/cm).(10) The public canals that provide flood control for the EAA cut into the shallow aquifer, which is highly mineralized and begins at a depth below the ground surface of only six to ten feet. Conductivities in this aquifer at a depth of 20 feet vary from about 500 umhos/cm to several thousand umhos/cm. From the 1940s to the 1980s there was an increase in the mineral content of the shallow aquifer due to the upward migration of groundwater, a response to removal of surface water by pumping for flood control.(33) During 1997-2003 the median conductivity at 10 farm canals within the EAA ranged from 770 to 1670 umhos/cm, as compared to 600 umhos/cm for Lake Okeechobee. The highest values within the EAA occur in the S-5A and S-6 basins.(34) During 1974 when water from the EAA was pumped into Lake Okeechobee, surface water conductivity was about 1000 to 1400 umhos/cm in canals within the EAA, with a decreasing gradient with distance into the lake such that conductivity decreased to about 500 to 800 umhos/cm toward the interior.(35)

Previous R-EMAP data indicated transport of high conductivity water in stormwater via canals well into the Everglades marsh.(9, 10) The highest conductivity observed in the 2005 wet season of over 1000 umhos/cm is within WCA 2 due to its proximity to the EAA and the influence of canal water and groundwater. Lower wet season conductivity in the western portions of WCA 3A (about 300 umhos/cm) and the interior of the Refuge (about 100 umhos/cm) indicate that generally these areas remain more influenced by rainfall. The highest conductivity values measured in the Refuge, 150 to 600 umhos/cm, all occurred at marsh stations in close proximity to the perimeter canal. During November 2005 median conductivities at the four pumps that provide flood control for the EAA (S-5A, S-6, S-7 and S-8) were 1482, 1406, 968 and 421 umhos/cm respectively, while the median conductivity in the discharge from Stormwater Treatment Area (STA) 2 into the Everglades was 1482 umhos/cm. [STAs are discussed in the section on nutrients.] High conductivity water is transported downstream in canals draining the EAA, and there is a progressive decrease

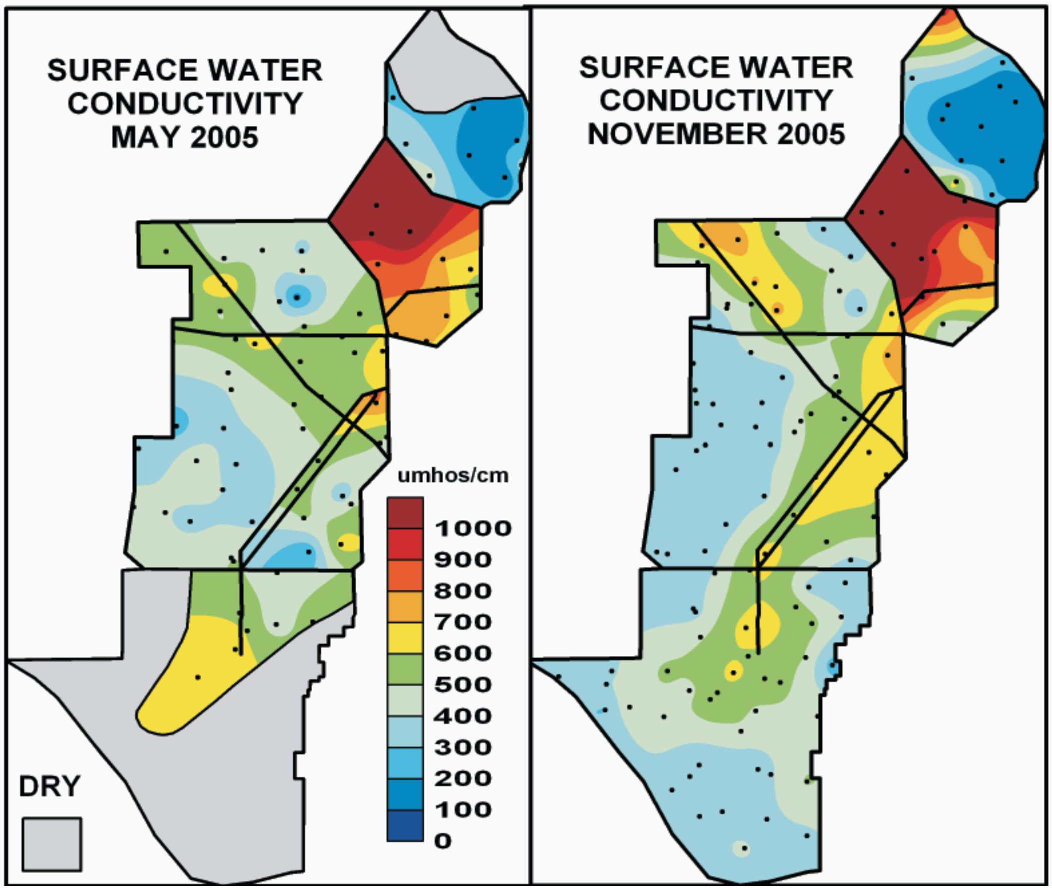


Figure 25. Surface water conductivity in marsh during the May 2005 dry season (left) and November 2005 wet season (right).

southward to the Park with dilution by rainfall and marsh water.(10) Marsh conductivity increases in the dry season due to lessening dilution by rainwater, evapo-concentration as the marsh dries out, and greater influence of canal discharges. Pronounced conductivity gradients clearly indicate pathways of water flow throughout the canal-marsh system and the extent to which the water management infrastructure and its operation influence water quality. From 1959 to 1974, as inflow to the Park at Shark Slough changed over time from being dominated by marsh sheetflow to canal discharge at the new S-12 structures, wet season mean marsh conductivity rose from 270 to over 500 umhos/cm.(36, 37) During 1978 to 1982, conductivity varied spatially such that at structure S-12A (Figure 24), a gated spillway that discharges water into the Park, conductivity averaged 303 umhos/cm, as compared to 1184 umhos/cm at S-7.(38) November 2005 Program data indicate that marsh conductivity is highly correlated with chloride and sulfate [Pearson correlation coefficients of 0.98 and 0.84, respectively (Appendix III)].

Florida's Class III water quality criterion for conductivity is that conductivity shall not be increased 50% above background, or exceed 1275 umhos/cm, whichever is greater. On an annual basis Florida consistently reports conductivity excursions that exceed the Class III criterion for the WCA 2A marsh, as well as for inflows to the Refuge and WCA 2A.(39) The Park and Refuge are also Outstanding Florida Waters, which further requires that the water quality condition that existed in these waterbodies during the year prior to March 1, 1979 must be maintained. Background conductivity within the interior of the Refuge is approximately 100 umhos/cm. The value of periphyton communities as a food source is affected by conductivity, in that increases in water ionic content can shift periphyton community structure.(25, 40, 131) Highly mineral water penetrates into the Refuge periphery. During 2004-2005 the median conductivity in the perimeter marsh was 329 umhos/cm, as compared to 118 umhos/cm at interior marsh locations.(41) Penetration of highly mineral water at 10 to 20 times background conditions into the Refuge marsh has been documented since the early 1970s,(42,43) when concern about the impact of this mineralized water on Refuge biota such as periphyton was also identified.(42,44) The Class III criterion of 1275 umhos/cm is not considered low enough to assure that mineral-induced shifts in periphyton communities will not occur in the Refuge. Recognizing this, CERP has adopted an Everglades protection and restoration performance measure for conductivity of no more than a 25% increase above background while taking into consideration natural seasonal and annual variation.(8) The expectation for restoration is that soft, low conductivity surface water will be maintained in the Refuge, while hard, higher conductivity water consistent with background will be maintained in the rest of the Everglades. However, given the inevitable groundwater-surface water interaction due to the very presence of canals, to some extent elevated surface water conductivity is unavoidable.

Chloride

The concentration of chloride varies throughout the Everglades depending upon the relative influence of rainwater, groundwater and stormwater. The Everglades does not have a surface water criterion for chloride. Chloride is a useful indicator of a water's source. Precipitation in the Everglades had a volume-weighted annual chloride concentration of 1.0 mg/L for 2005.(32) During the November 2005 wet season sampling, the lowest chloride concentrations of 16 mg/L to 18 mg/L were observed in the interior of the Refuge and southwestern WCA 3 away from canal inflows, while the highest concentration of 260 mg/L was observed in WCA 2 (Figure 26). During November 2005 the median chloride concentration at flood control pump S-6, which pumps water from the EAA into STA 2, was 194 mg/L, while the median chloride concentration in the discharge from STA 2 into WCA 2 was 199 mg/L. Concentrations at S-7 and S-8 are lower.(SFWMD data) These concentrations are similar to those reported during 1974-1976: 177 mg/L at S-5A and 186 mg/L at S-6.(45) During 2004-2005, the median chloride concentration in the Refuge interior was 23 mg/L, with a higher concentration of 47 mg/L in the marsh near the perimeter due to penetration of mineral water from the surrounding canal.(41)

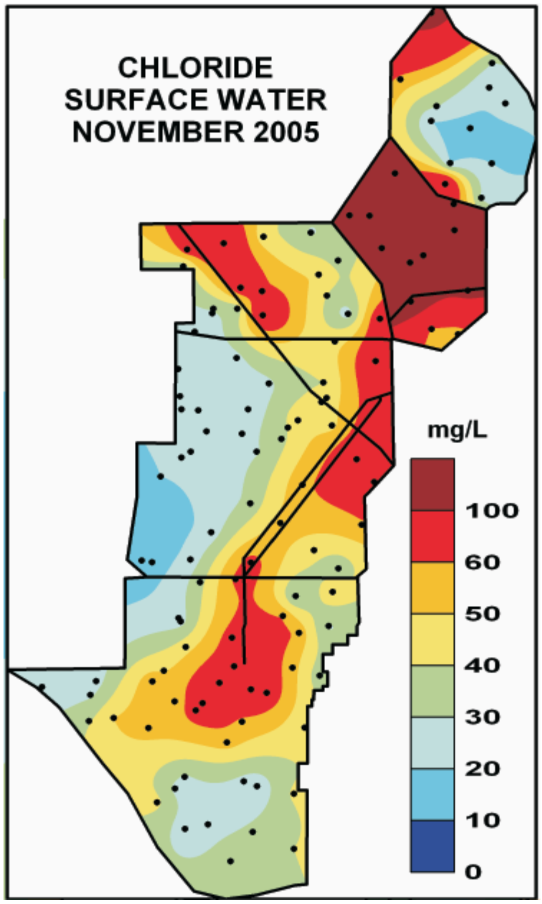


Figure 26. Surface water chloride concentration (mg/L) during the Novermber 2005 wet season.

The chloride concentration in the shallow aquifer within the EAA at a depth of 20 feet is reported at generally between 100 to 200 mg/L. The chloride concentration within this shallow aquifer increased from the 1940s to the 1980s due to the upward migration of ground water in response to pumping for flood control.(33) During 1999-2003 the median chloride concentration at 10 farm canals within the EAA ranged from 72 to 174 mg/L.(34) From 1959 to 1974, as inflow to the Park at Shark Slough changed over time from being dominated by marsh sheetflow to canal discharge at the new S-12 structures, canal chloride concentration

Pronounced spatial gradients in surface water conductivity, sulfate and chloride throughout the canal and marsh system vividly demonstrate that the canal system is a conduit for transport of pollutants. This transport is an unintended consequence of the flood control project.

rose from about 20 mg/L to about 60 mg/L.(46)

Chloride concentration in the STA 1 West outflow generally varied between 100 to 200 mg/L from 1994-1999. As expected there was no removal of this conservative constituent by this wetland treatment system.(47) For Water Year 2006 (WY, May 1, 2005 to April 30, 2006), STA 1W, STA 2, STA 3/4, and STA 5 discharged dissolved chloride at concentrations of 142 mg/L, 157 mg/L, 73 mg/L and 33 mg/L respectively, with no removal by the STAs.(48)

SULFATE AND SULFIDE

Sulfur is an element that exists in several forms in water bodies. Sulfur generally occurs in surface water in the oxidized state as sulfate, an ion that is common in nature. It is a natural ingredient of rainfall, surface water and groundwater. The common reduced form of sulfur is sulfide, which is associated with sulfate reduction by anaerobic bacteria. Sulfur is also a secondary nutrient required for crops. Sulfur is of particular interest in the Everglades for three reasons: sulfate and sulfide have been implicated as factors in mercury methylation and subsequent bioaccumulation;(49,50,56) elevated sulfate has been shown to mobilize phosphorus in water bodies;(51-54) and sulfide in elevated concentrations can be toxic to plants(51-53) and animals. Because of these ecological concerns CERP has adopted the following performance measure for surface water sulfate: maintain or reduce sulfate concentration to 1 milligram per liter (mg/L) or less throughout the Everglades marsh.(8)

There are no numeric water quality criteria for sulfate or sulfide in the Everglades. Nationally, USEPA does not have a recommended surface water criterion for sulfate. For sulfide USEPA recommends a surface water criterion of 0.002 mg/L for protection of aquatic life,(55) while there are no water quality criteria recommended for sulfide in pore water. Florida has not adopted water quality criteria for sulfate or sulfide. However, Florida has designated the Park and Refuge as Outstanding Florida Waters, requiring that the water quality that existed

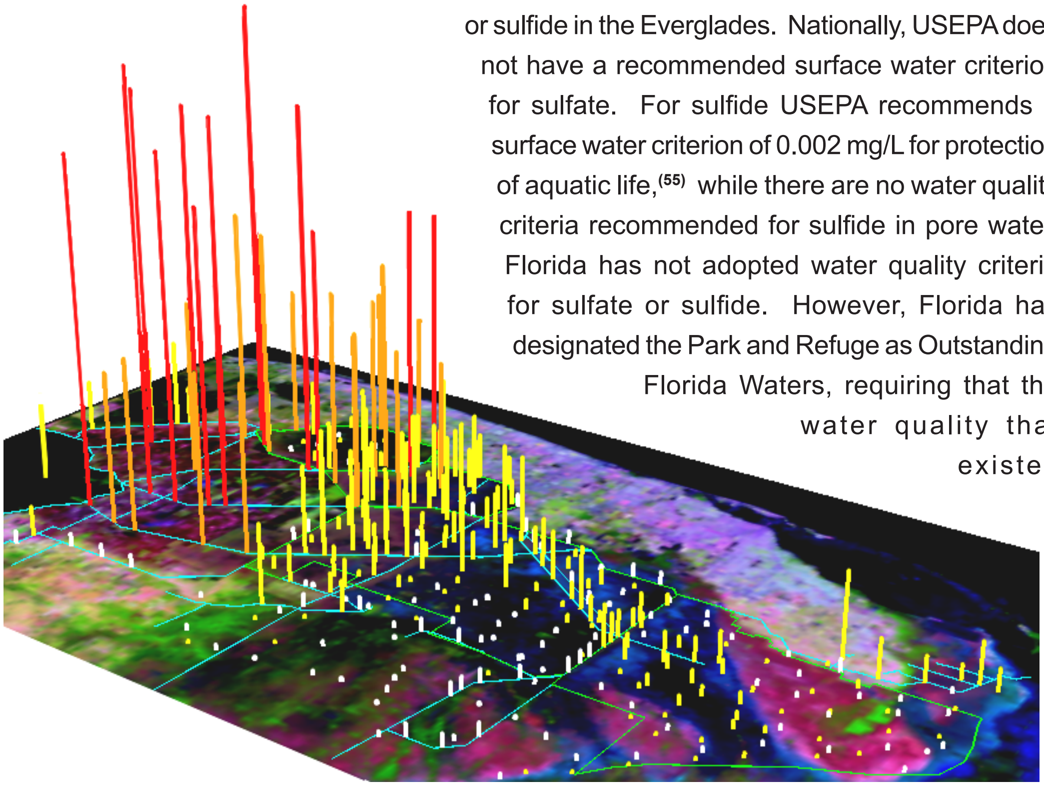


FIGURE 27. Surface water sulfate in the marsh and canal system during the 1993-1996 R-EMAP wet season sampling events. White dots indicate sulfate was below lab analytical detection limits, which varied from 0.5 to 5 mg/L, yellow bars indicate sulfate was detected by the lab at <50 mg/L, orange bars indicate sulfate is 50 to 100 mg/L, red bars indicate sulfate >100 mg/L. The median wet season concentration in southern Lake Okeechobee during these years was 31 mg/L.

as of March 1979 be maintained. In addition, although there are no numeric sulfur criteria for the Everglades, Florida water quality standards state that "Substances in concentrations which injure, are chronically toxic to, or produce adverse physiological or behavioral response in humans, plants or animals – none shall be present."(123) The stimulation of mercury (Hg) methylation by sulfate enrichment and subsequent Hg bioaccumulation to levels that necessitate fish consumption advisories is relevant. Toxic or inhibitory effects of sulfide on plants are also relevant.

Sulfate concentration varies throughout the Everglades depending upon proximity to the EAA and the relative influence of rainwater, stormwater and groundwater. The annual volume-weighted sulfate concentration in rainfall within the Park for 2005 is reported at 0.70 mg/L. It was lower, 0.54 mg/L, during the June to August months that accounted for 57% of the annual precipitation.(32) Annual mean and median sulfate in rainfall for the three Everglades locations sampled by SFWMD were all less than 1.0 mg/L for WY2005 (Figure 29). Interior portions of the Park, Refuge and WCA 3 that are most influenced by rainfall had sulfate concentrations in surface water near analytical laboratory method detection

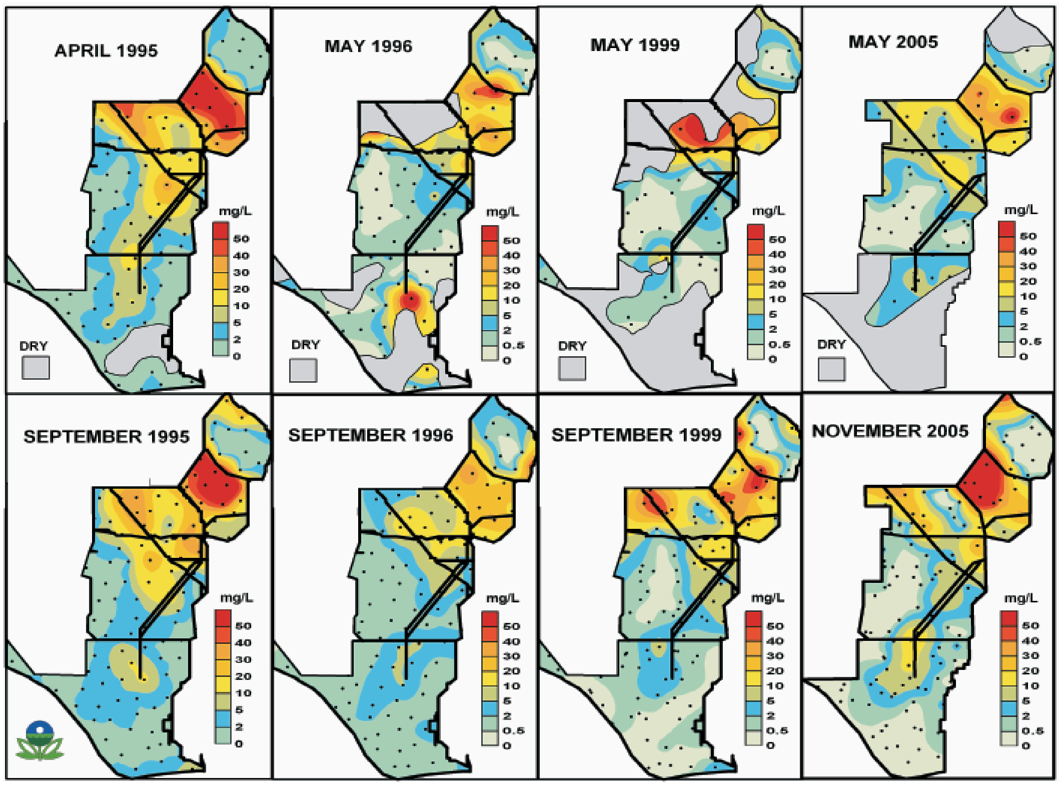
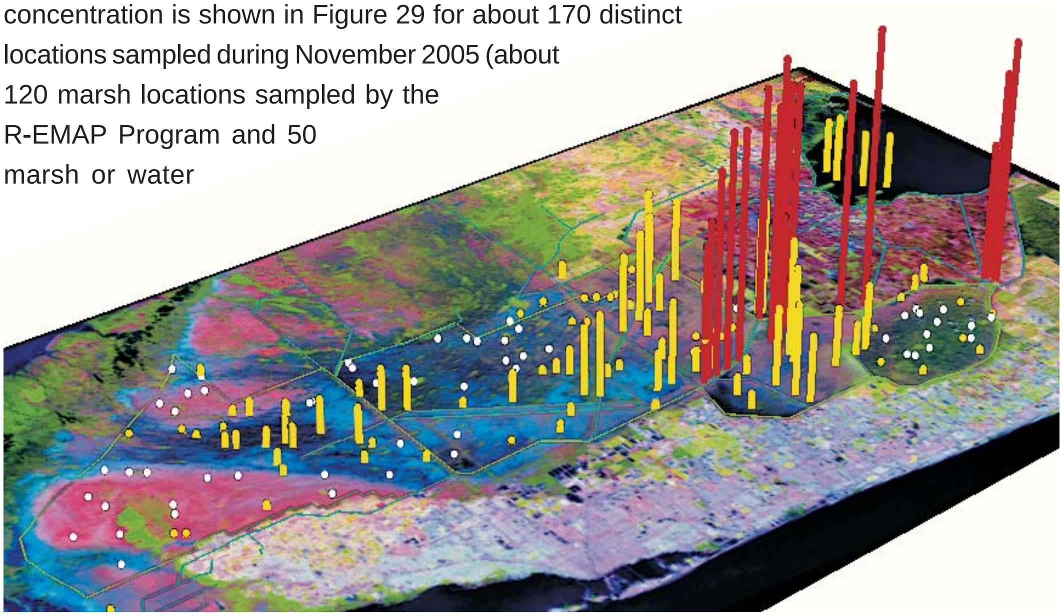


FIGURE 28. Surface water sulfate concentration (mg/L) in the Everglades marsh during the dry season (top) and wet season (bottom) sampling events from 1995-2005.

limits of about 0.1 mg/L during November 2005 (Figures 29 and 30). During November 2005 the median sulfate concentration was 0.2 mg/L at the 39 R-EMAP stations depicted in Figure 30 as being <1 mg/L. Some marsh interior stations distant from canals within the Park (P37 and P34) and Refuge (LOX9) had 2002-2006 median sulfate concentrations of 0.1 mg/L, the analytical detection limit (Figure 30). This indicates that at certain Everglades locations the marsh background sulfate concentration may be even less than the analytical detection limit of 0.1 mg/L.

In contrast, the highest marsh concentrations are at locations that are proximate to canals or stormwater discharges from the EAA. The R-EMAP Program previously documented pronounced marsh and canal surface water sulfate gradients and seasonality during 1993 to 1996 (Figure 27).[(10)] Figure 28 shows surface water sulfate concentration in the marsh for each of the Program sampling events from 1995-2005. Surface water sulfate concentration is shown in Figure 29 for about 170 distinct locations sampled during November 2005 (about 120 marsh locations sampled by the R-EMAP Program and 50 marsh or water



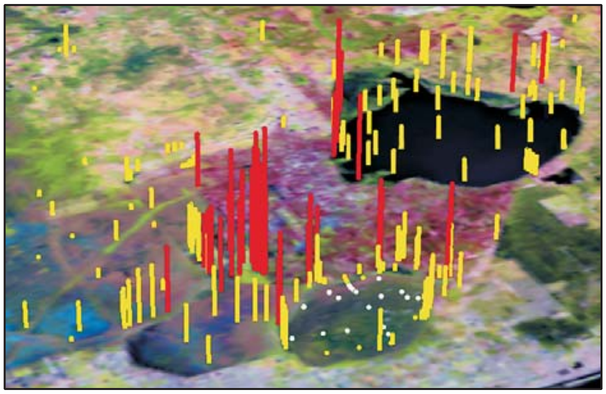


Figure 29. *Above:* Surface water sulfate in the marsh during the November 2005 wet season. *Right:* Mean annual WY2006 sulfate concentration at locations sampled by SFWMD. White dots indicate sulfate <1 mg/L, yellow bars indicate sulfate is 1 to 50 mg/L, red bars indicate sulfate >50 mg/L. EAA canals were not sampled during 2005.

management structure locations sampled by SFWMD). The highest sulfate concentrations of over 100 mg/L were observed in canals within the EAA during the wet season and in the Water Conservation Area 2A marsh. During the 60 days prior to the November 2005 Program sampling, the four structures that provide flood control for the EAA discharged about 343,500 acre-feet of water into the EPA. The wet season sulfate concentrations at these structures closest in time to the R-EMAP sampling event are as follows: S-5A,131 mg/L; S-6, 136 mg/L; STA 2 outflow at G-355, 106 mg/L; S-7, 86 mg/L; S-8, 21 mg/L and S-9, 2 mg/L. This compares to concentrations during 1974-1976 of 92 mg/L at S-5A, 32 mg/L at S-6, 39 mg/L at S-7 and 29 mg/L at S-8.**(45)** During 1997-2003 the mean sulfate concentration at 10 farm canals within the EAA ranged from 45 mg/L to 119 mg/L. The highest concentration occured in the eastern EAA in the S-2/S-6 basin.**(34)** Sulfate concentrations in southern Lake Okeechobee during November 2005 were about 22 mg/L (Figure 29). Concentrations in the Everglades progressively decrease to the south and west. These spatial patterns indicate that the canal system delivers sulfate from the north into Everglades marshes. Penetration

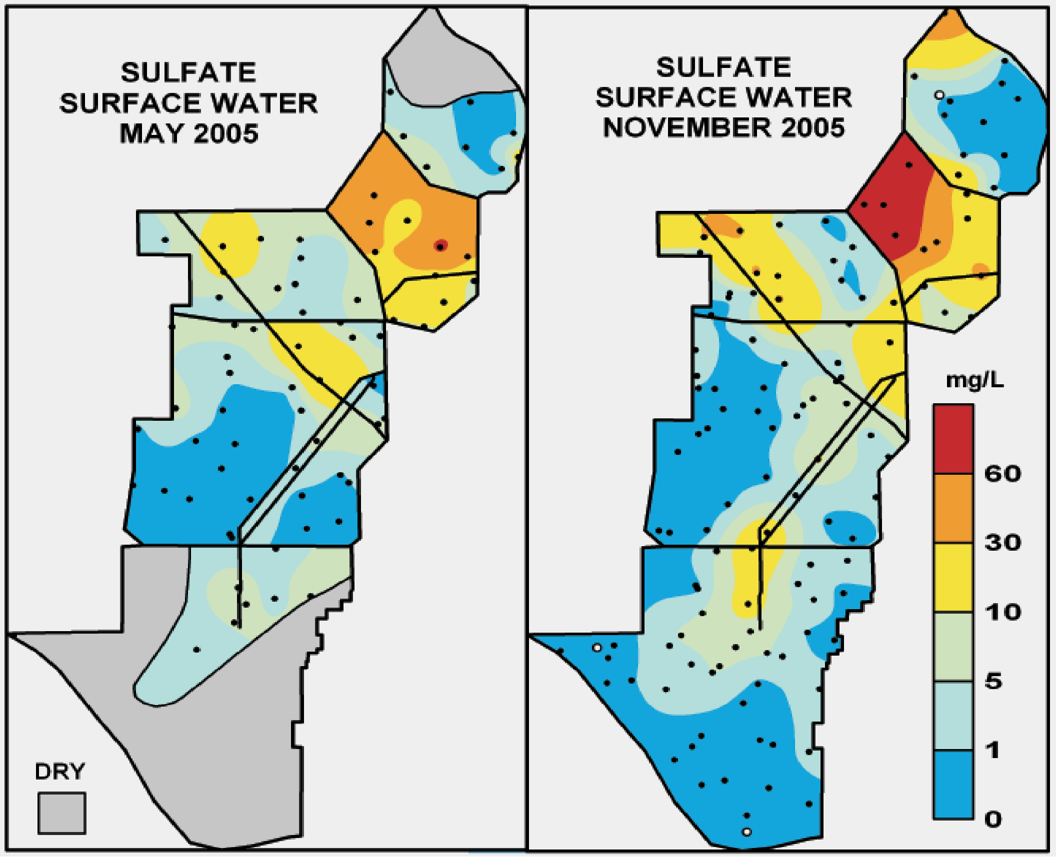


Figure 30. R-EMAP surface water sulfate concentration (mg/L) during May 2005 (left) and November 2005 (right). Three fixed stations with median annual sulfate < 0.1 mg/L are shown by white circles (right, data from SFWMD).

of sulfate well into the Shark Slough marsh of the Park is evident (Figures 27-30).

The concentration of sulfate in Everglades groundwater has been reported by various investigators. Sampling of the surficial aquifer underlying the EAA at about 20 locations in 1983-84 indicated sulfate concentrations of 25 mg/L to 580 mg/L at a groundwater depth of 45 feet(33), about 20 feet below the depth that the major canals penetrate. The highest concentrations were in the eastern EAA in the area of the S-2 /S-6 basins. A 1976-77 study of water quality in the EAA reported sulfate at 20 mg/L to 490 mg/L in shallow groundwater, with mean concentrations of 153 mg/L below sugarcane and 199 mg/L below vegetables. The mean surface water concentrations ranged from 40 mg/L to 459 mg/L.(124) In contrast, the median groundwater concentration in 189 wells tapping the Biscayne Aquifer was 17 mg/L.(122) The Biscayne Aquifer is the shallow, unconfined, highly-permeable aquifer underlaying the Everglades and southeast Florida.

Agricultural sulfur (S) has been applied to EAA soils for various purposes. The sulfur content of EAA peat soils is considered adequate to supply some S requirements. However, surface application of S has been recommended when soil pH is > 6.6 in order to increase plant nutrient availability, with a recommended application rate of 500 pounds S per acre.(57,58) A 1976-77 study of water quality in the EAA reported S application of 10 pounds per acre to sugarcane and 78 pounds per acre to vegetables.(124) EAA soils have been prone to copper deficiency, which has been addressed by treatment with copper sulfate. Magnesium has been commonly supplemented by use of fertilizer blends containing potassium-magnesium sulfate.(59)

Using data collected from 1995-1999, other investigators analyzed sulfur concentrations and isotopic ratios for rainwater, EAA groundwater, and EAA fertilizer, concluding that excess sulfate in the Everglades originates from canals draining the EAA.(61) The sulfate concentration and isotopic data appear to exclude rainwater and some ground water as major contributors. Isotopic evidence implicates agricultural fertilizer as a major contributor to the sulfate load. This fertilizer could be recent additions, legacy additions, or some combination of both. However, EAA groundwater and oxidation of agricultural soil may also contribute sulfate.(61) It has been reported that, based on isotopic composition, groundwater is not a major source of sulfate to surface water in WCA 2A.(62)

The wetland STAs constructed and managed to remove phosphorus remove varying amounts of sulfate. STA 1W is reported to have exhibited moderate removal of sulfate from 1994 to 1999 (Figure 42).(47) During WY2006, for the STAs the flow-weighted sulfate inflow concentration, flow-weighted outflow concentration and percent removal were as

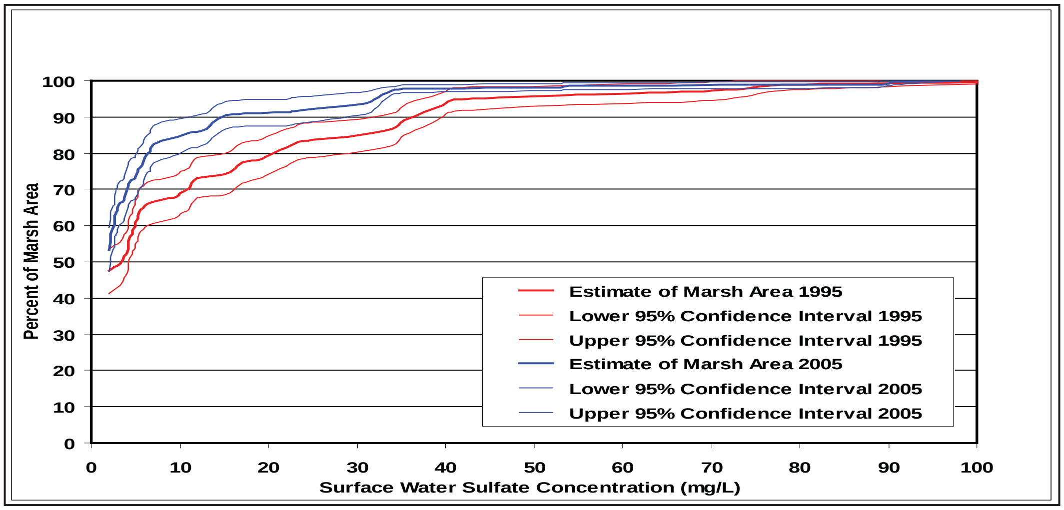


FIGURE 31. Wet season 1995 (red) and wet season 2005 (blue) marsh surface water sulfate cumulative distribution function (cdf) with the upper 95% and lower 95% confidence interval for marsh area. .

follows: STA-1W 73 mg/L, 69 mg/L, 5%; STA-2 103 mg/L, 76 mg/L, 26%; STA-3/4 53 mg/L, 43 mg/L, 19%; STA-5 7 mg/L, 4 mg/L, 43% and STA-6 15 mg/L, 5 mg/L and 67%. Sulfate removal by the STAs is highly variable (5% to 67%) and appears to be a function of inflow concentration. The highest STA inflow sulfate concentrations occured in the S-5A and S-6 basins (73 mg/L and 103 mg/L respectively).(48) The eastern EAA and the S-5A, S-2 and S-6 basins consistently have the highest concentrations of sulfate in groundwater and surface water. Elevated sulfate has been shown to mobilize phosphorus in waterbodies.(51-54) If the high sulfate within in the STAs mobilizes phosphorus, this would limit STA performance, especially for STAs 2, 1W, and 3/4. This issue has not been fully evaluated.

Based on the cumulative distribution function (cdf) of R-EMAP data, during November 2005 the proportion of the Everglades marsh where sulfate exceeded the 1.0 mg/L restoration goal was 57.3 ± 6.0% (Figure 31). This compares to 66.1 ± 7.0% during 1995. Statistical testing for differences between these cdf curves confirm that these proportions are significantly different. The average concentration was less in 2005 than in 1995 as well. These differences cannot be explained by dilution since the lower concentrations observed during the 2005 wet season occured in shallower water than in 1995 (Figure 23). Stormwater is a possible explanation, as stormwater inflow to the EPA in the 60 days prior to the 1995 wet season sampling was double the inflow during the 60 days prior to the 2005 wet season sampling (Table 2). These differences in sulfate concentration, though real (in a statistical sense), are subtle. Further analyses, such as additional corroboration of the R-EMAP data with records from fixed stations, and normalizing the data by water depth, are planned. These analyses may clarify the effect of variation at multiple time scales that are

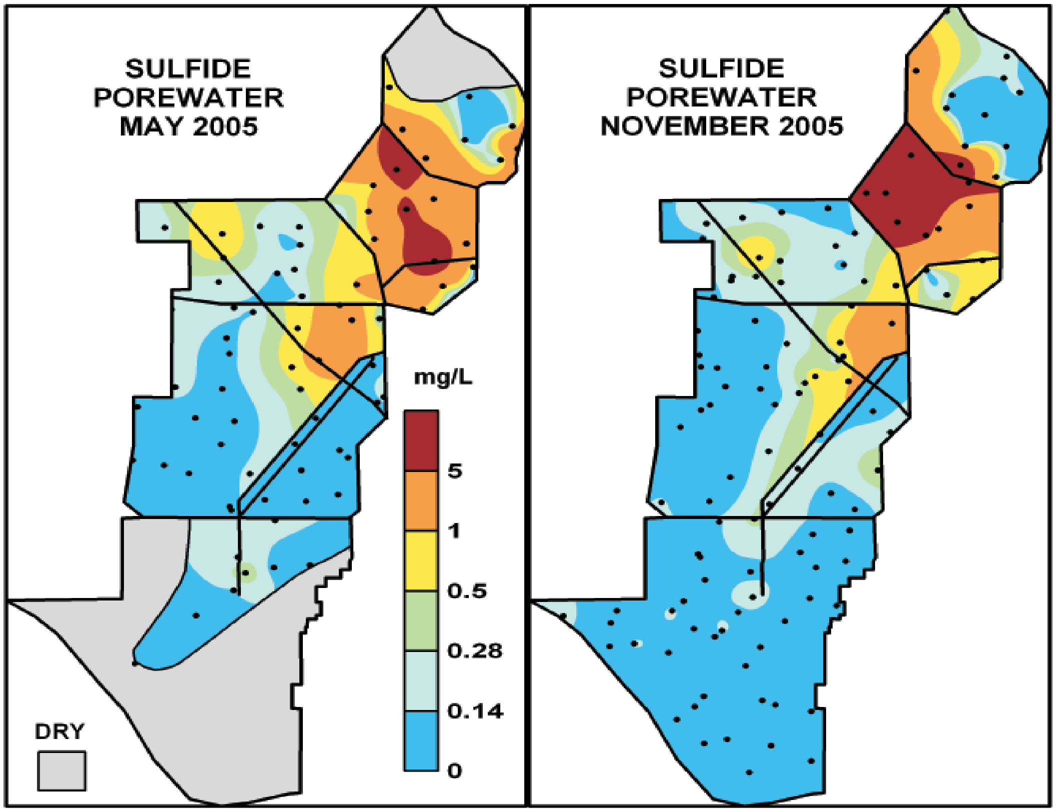


FIGURE 32. Sulfide concentration in pore water during May 2005 (left) and November 2005 (right).

shorter than the frequency of R-EMAP sampling. These same considerations are applicable to other analytes in surface water.

Sulfide concentration in porewater during 2005 also indicated pronounced spatial gradients (Figure 32). Under anaerobic conditions sulfide is formed from sulfate. Sulfur speciation and isotopic composition of Everglades plant materials suggests that sulfate reduction is occurring in the periphyton mat.(60) Background sulfide concentrations throughout portions of the Everglades marsh remote from canal inflows are less than 0.14 mg/L. In contrast, pore water sulfide exceeded 1 mg/L, and even 5 mg/L, at several locations in WCA 2A. High sulfide can inhibit mercury methylation(50,63), but it can also be toxic to macrophytes.(52) These elevated concentrations in WCA 2A are consistent with those reported to inhibit the growth of sawgrass.(24) The area of maximum sulfide concentration in porewater coincides with the area of maximum sulfate concentration in surface water (Figures 30 and 32). Porewater sulfide was correlated with sulfate in surface water and porewater, and with mercury in surface water, periphyton and sediment ($p<0.001$) [Appendix III]. Porewater sulfide was negatively correlated with mercury bioaccumulation ($p<0.001$).

ORGANIC CARBON

Organic matter is important for various biological and chemical processes. Carbon can influence the availability of nutrients and serve as a substrate for microbial reactions. Carbon is abundant in the Everglades because of the extensive peat soils that are as much as 90% organic matter (Figures 36, 38 and 39). During 1993 to 1996 the Program previously documented distinct spatial gradients in surface water organic carbon in canals and in the marsh, with the highest concentrations observed in canals within the EAA.(10) The origin of this carbon is most likely the peat soils of the EAA, with export in stormwater due to flood control pumping. During 1974 when water from the EAA was pumped into Lake Okeechobee, surface water Total Organic Carbon (TOC) was about 90 to 106 mg/L in canals within the EAA, with a decreasing gradient with distance into the lake such that TOC decreased to about 20 to 50 mg/L toward the interior.(35)

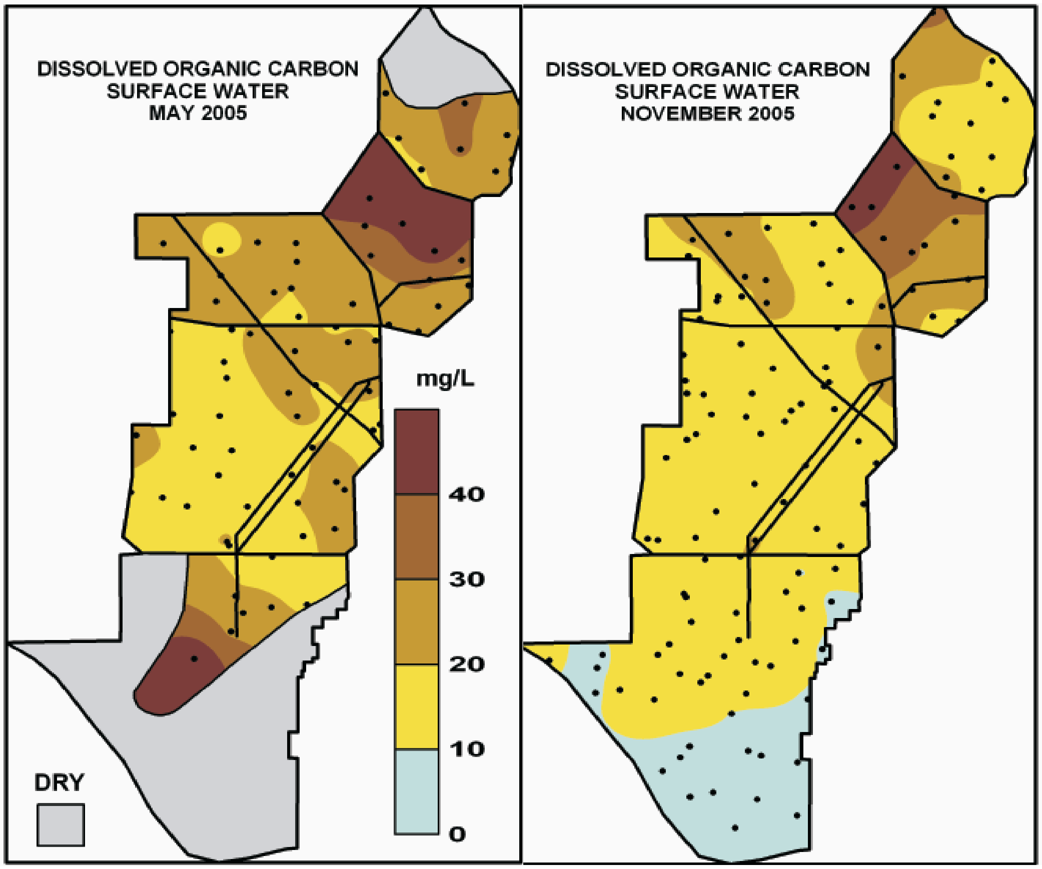


FIGURE 33. Surface water dissolved organic carbon during May 2005 (left) and November 2005 (right).

During 2005, Program data show that Dissolved Organic Carbon (DOC) in the Everglades exhibited a spatial gradient and high seasonality with higher values found during the dry season (Figure 33). The lowest DOC concentrations of 4 mg/L to 10 mg/L were all found during the wet season within the portions of the Park where marl soils of low organic content occur. From 1994 to 1999 STA-1W exhibited no net removal of carbon, with about 93% of the surface water TOC in the dissolved fraction.(47)

Carbon is of interest in that it plays a role in mercury cycling. Dissolved organic matter binds mercury, affects mercury solubility and can influence mercury availability to microbes that methylate mercury. Areas strongly influenced by EAA stormwater have higher dissolved organic matter concentrations and are more reactive with mercury than more pristine areas of the Everglades.(64) During the November 2005 Program sampling, DOC had a significant negative correlation with mercury bioacculation factor [Pearson correlation coefficient of - 0.65, p<0.001 (Appendix III)].

Figure 34. Surface water samples collected during Phase I canal sampling. Samples with more color were collected at locations within or near the EAA. Samples with more color had higher carbon content.

pH

The logarithm of the reciprocal of the concentration of free hydrogen ions is refered to as pH. The pH of pure water is 7.00, or neutral. Increased hydrogen ion activity lowers the pH toward acidity, while decreased activity increases the pH toward becoming basic. The pH of unpolluted water is usually between 6.5 and 8.5.(31) Rainwater in the Everglades had a precipitation-weighted mean pH of 5.0 for 2005.(32)

In-situ surface water pH and soil pH varied spatially during November 2005, in similar fashion (Figure 35). The soft-water Refuge has low capacity to buffer against acidity (annual median alkalinities at interior locations as low as 8 mg as calcium carbonate per liter), while the hard waters of the Park have high buffering capacity (annual median alkalinities of about 200 mg as calcium carbonate per liter).(39) The marl soil found throughout much of the Park (Figures 36 and 39) contributes to this buffering capacity and results in higher

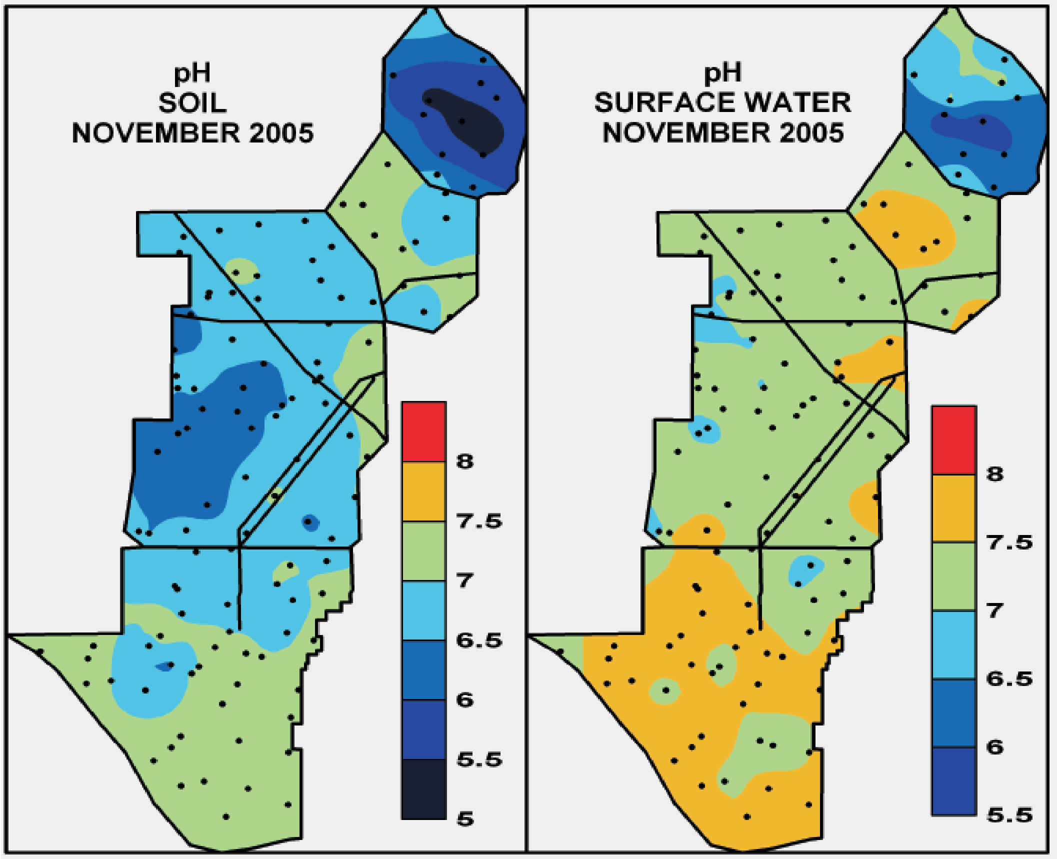


Figure 35. In-situ surface water pH (right) and in-situ soil pH (left) during November 2005.

pH values. The lowest surface water pH of 5.66 measured for the Program from 1995-2005 was encountered in the Refuge during the morning, and the highest pH of 8.39 was encountered in the the Park during the morning. Surface water dissolved oxygen throughout the marsh varied from 0.3 to 13.6 mg/L. In-situ soil pH exhibited a spatial pattern with the lowest pH within the interior portion of the Refuge with highly organic soils and the highest pH generally within the marl soils of the Park.

Photosynthesis by aquatic organisms removes carbon dioxide from the water column during daylight hours, resulting in an increase in surface water pH.(31,42) In a natural wet prairie community in the Park, with bladderwort and an extensive calcareous periphyton mat, the pH at one location was shown to fluctuate over 24 hours from 7.1 at midnight to 8.5 late in the afternoon.(65) Given that during November 2005 measurements of in-situ water pH for the Program occurred between 0800 and 1700 hours, and Program sampling took place from south to north over a ten day period, the observed spatial pattern in pH cannot be explained by diurnal fluctations.

The Everglades has a water quality criterion for pH of not <6.0 or >8.5. The Program includes 15 of 736 pH measurements that were less than 6.0. All were in the interior of the Refuge. Florida has routinely reported violations of the pH criterion within the most interior portion Refuge where values lower than 6.0 are found, but these excursions below the criterion are viewed as a consequence of the Refuge’s naturally low alkalinity and are not of ecological concern.(39)

SOILS and SOIL SUBSIDENCE

Soil is a key defining characteristic of an ecosystem, and soil preservation is an important aspect of ecosystem protection. The Comprehensive Everglades Restoration Plan has adopted objectives, performance measures, and performance targets 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.(8)

There are two major soil types in the Everglades. The wetland soils of the central Everglades are primarily peat (Figures 5 and 36) formed by slowly decaying plant matter. The other major soil type found within Everglades wetlands is calcitic mud or marl (Figure 36) commonly found in the shallower peripheral marshes of the Everglades that are subjected to shorter periods of surface water inundation. Marl is found in association with thick, calcitic algal mats (periphyton) (Figure 36), which precipitate calcium carbonate from the water column.(66)

Figure 36. Everglades peat (top) and marl (bottom). Bottom photo also shows a benthic periphyton mat overlaying the soil core.

The Everglades are reported to have 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.(67) The origin and perpetuation of peat and marl soils are greatly dependent upon water depth, 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. Some soil cores collected for the Program have alternating peat and marl layers within the 0-10 cm profile.

Peat soils are subject to subsidence and loss of surface elevation 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, or within a few hours if dry soils are subjected to fire.

From the 1940s to the 1990s, over one-half of the soil was lost from portions of the Everglades. Water management must continue to improve in order to maintain marsh soils and the plant communities and wildlife habitat of these wetlands.

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.(68) Subsequent subsidence within the EAA and efforts to control it on agricultural lands are well documented. In 1912 much of the EAA had soils thicker than 10 feet.(67,68) By 1988 only 17% of the EAA had soil thicker than 51 inches, while 53% of the area had soils less than 36 inches thick, and 11% had soils less than 20 inches thick. By 2050, under current agricultural practices, about 93% of the EAA is projected to have soils less than 36 inches thick and about 53% is projected to have soil less than 8 inches thick.(121) Based on these soil thickness projections, the decrease in soil volume within the EAA from 1988 to 2050 is calculated to be 57% or 11.7×10^8 m^3. The fate of certain constituents of this soil, such as phosphorus, sulfur and mercury, are of potential concern for the downstream Everglades.

Within the EAA, production of agricultural crops such as vegetables and the more prevalent varieties of sugarcane require that the water table be maintained below the ground surface. The ground surface of the EAA basin, which historically was sawgrass marsh that flooded much of the year, is now several feet below that of circa 1910 due to subsidence. Frequent rain events during the wet season necessitate repeated pumping in order to maintain the water table below the ground surface, which continues to subside further. Each of these flood control pumping events has the potential to leach and export soil constituents, such as phosphorus, nitrogen, sulfur and carbon, in the stormwater pumped southward to the Everglades. Agricultural Best Management Practices are directed at phosphorus removal. The STAs are more effective at removing phosphorus than nitrogen, sulfur or carbon. Given the projection, if realized, that one-half of the EAA may have less than 8 inches of soil by 2050, the viability of agriculture with current practices comes into question.(121) If residential land use requires that the water table be maintained at even lower levels, conversion from agriculture to residential land use could result in the need to export greater volumes of stormwater to the Everglades.

Soil loss in the Everglades was 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 southward 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 compartmentalized the Everglades into the Water Conservation Areas. By the 1960s

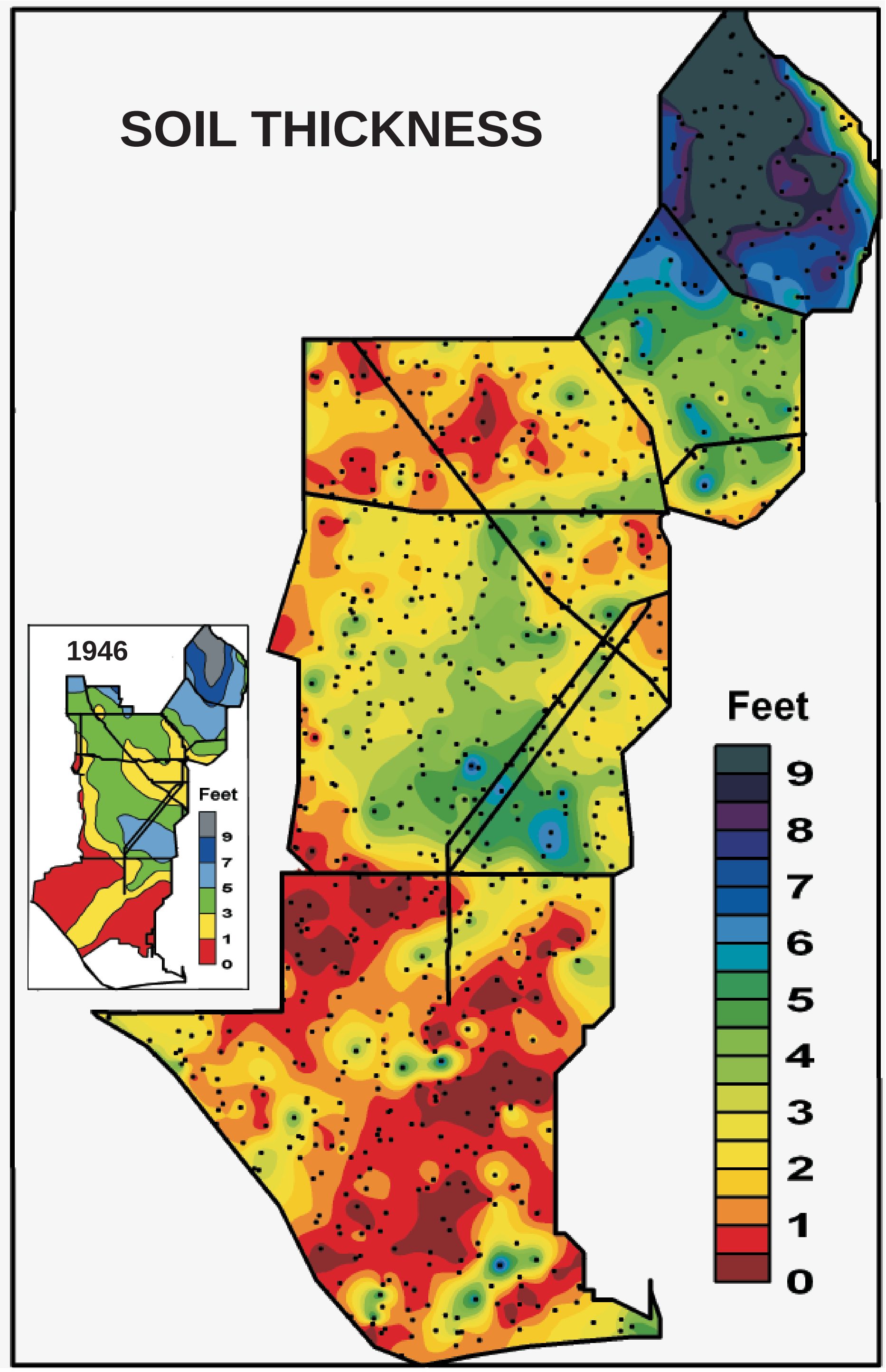


Figure 37. Soil thickness measured at 867 locations during R-EMAP Phases I, II and III from 1995-2005. The inset shows soil thickness as reported in 1946.[70]

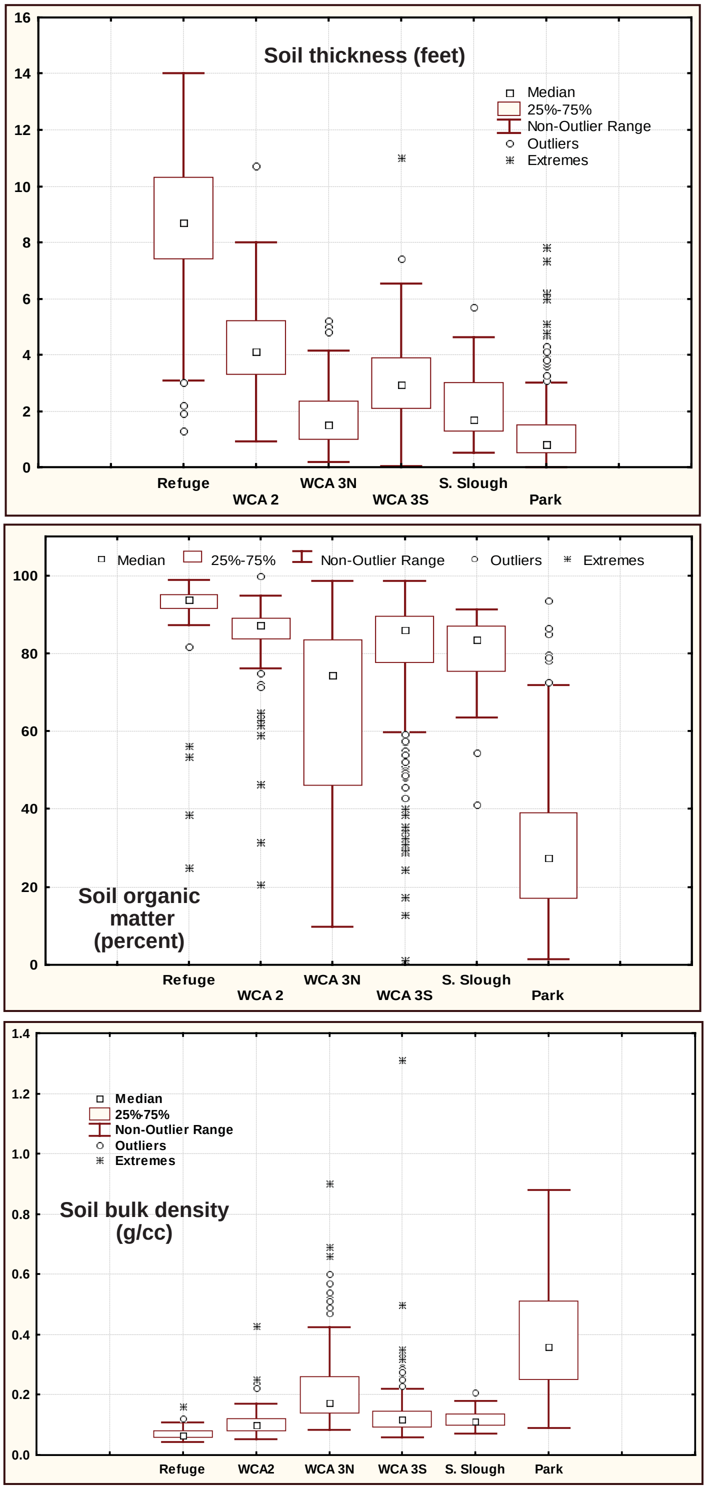


FIGURE 38. Soil thickness (top), percent organic matter (middle) and bulk density (bottom) by Everglades sub-area for soil cores at 0-10 cm.

Everglades surface water depths, flow, and inundation periods had been greatly altered.(69)

The R-EMAP Program was the first to consistently document soil thickness, bulk density and organic matter throughout the Everglades system. The Program previously documented soil subsidence in the public Everglades.(10) Comparisons of Everglades soil thicknesses measured in 1995-1996 to those reported by Davis in 1946(70) indicated that short hydroperiod portions of the Everglades such as WCA 3 north of Alligator Alley (Figures 40 and 41) lost 39% to 65% (2.0 to 6.0 x 10^8 m^3) of its soil. Soil thicknesses of 3 to 5 feet in the 1940s had diminished to only 1 to 3 feet by 1995-1996, with less than 1 foot remaining in some areas. WCA 3B and the Northeast Shark Slough portion of the Park were found to have lost up to 3 feet of soil, representing a 42% and 53% loss of volume, respectively. These three portions of the Everglades, about 200,000 acres, have been subjected to decreased surface water inundation since completion of the Water Conservation Areas about 50 years ago (Figures 23 and 40). It has been established that from the 1940s to 1990s the entire Everglades Protection Area lost up to 28% of its soil volume due to oxidation and subsidence.(10)

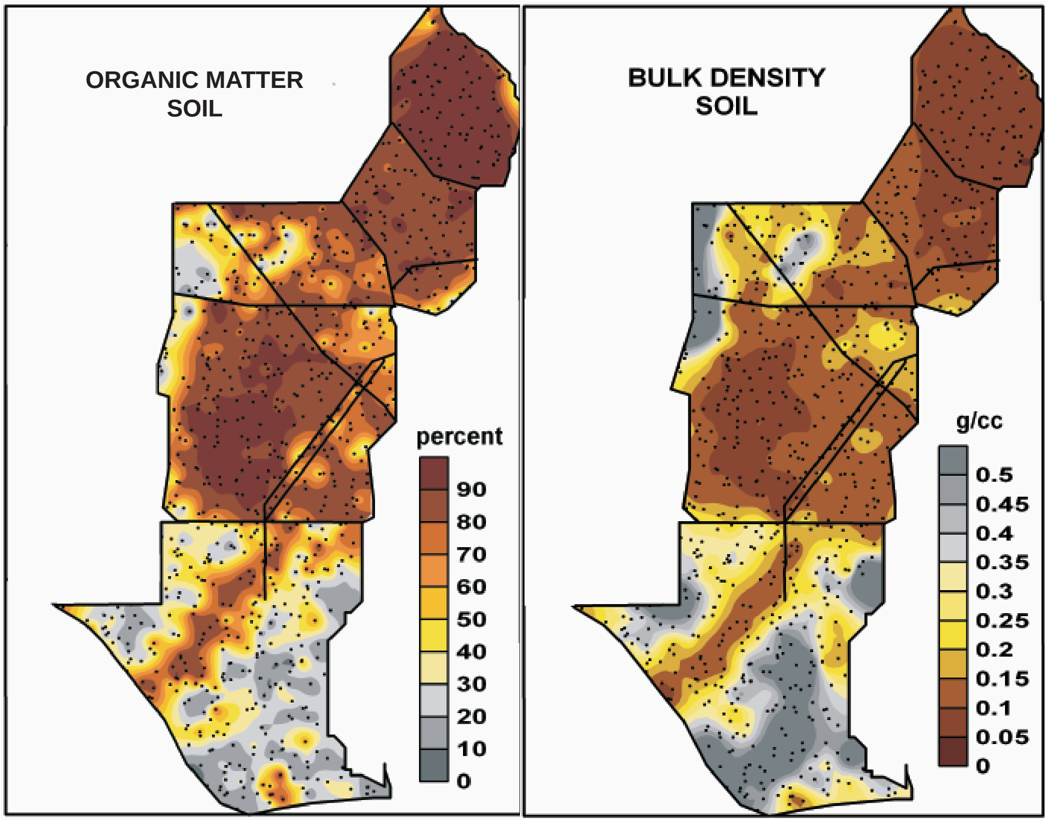


FIGURE 39. Soil percent organic matter (left) and bulk density (right) for soil cores at 0-10 cm.

The R-EMAP Program continues to be the only source of soil thickness data throughout the Everglades post-1940s.

Krigs of soil thickness measured for the Program in 1995-1996, 1999 and 2005 suggest no discernable difference among sampling events. Soil thickness data for 1995-2005 at 867 sampling sites are shown in Figure 37. The deepest soils are the peat deposits within the Refuge, with a median soil thickness of 8.7 feet (Figure 38). Median soil thicknesses for remaining portions of the study area were 4.1 feet in WCA 2, 1.5 feet in WCA 3A north of Alligator Alley, 2.9 feet in WCA 3 south of Alligator Alley, 0.82 feet in the Park excluding Shark Slough, and 1.7 feet in the longer hydroperiod portion of Shark Slough (SS) within the Park. The overall median soil thickness for the Everglades is 2.3 feet. As of 2005 the volume of soil in the freshwater Everglades study area was 4.0 x 10^9 m^3. About 25.1 ± 2.0% of the Everglades had a soil thickness less than one foot, while 36.1 ± 2.1% had a soil thickness of over three feet. The deepest peat in the Everglades outside of the Refuge is in those portions of WCA 2 and southern WCA 3 which typically stay inundated year-round. Most of the Park has a soil thickness of less than 1 foot, as does a portion of northern WCA 3.

Soil organic matter observed during 1995 to 2005 at 862 sites ranged from <1% to

100% (Figures 38 and 39), with a median of 80%. Peat soils are highly organic, while marl soils are primarily mineral. The highest organic matter content was found in the thick peat soils of the Refuge, having a median of 94%. WCA 2A and WCA 3 south of Alligator Alley also had soils exceeding 75% organic matter. These highly organic zones coincide with the longer hydroperiod portions of the system. The area of maximum soil loss within WCA 3 north of Alligator Alley had a median soil organic matter content of 63%, the lowest in the Water Conservation Areas. The peat soils in the Shark Slough trough of the Park had a median organic matter of 83%, in contrast to the marl soils of the Park which have a median of only 27%.

Soil bulk density, the mass of dry soil per unit of bulk volume, ranged from 0.04 to 1.30 g/cc (Figures 38 and 39). The highly organic peat soils of the Refuge had the lowest bulk density, with a median of 0.06 g/cc, in contrast to the marl soils of the Park which had a median of 0.36 g/cc. The median soil bulk density for WCA 3 north of Alligator Alley (Figure 41) was 0.17 g/cc, the highest in the Water Conservation Areas. Within the Water Conservation Areas, this portion of northern WCA 3 had the lowest organic matter content, the highest

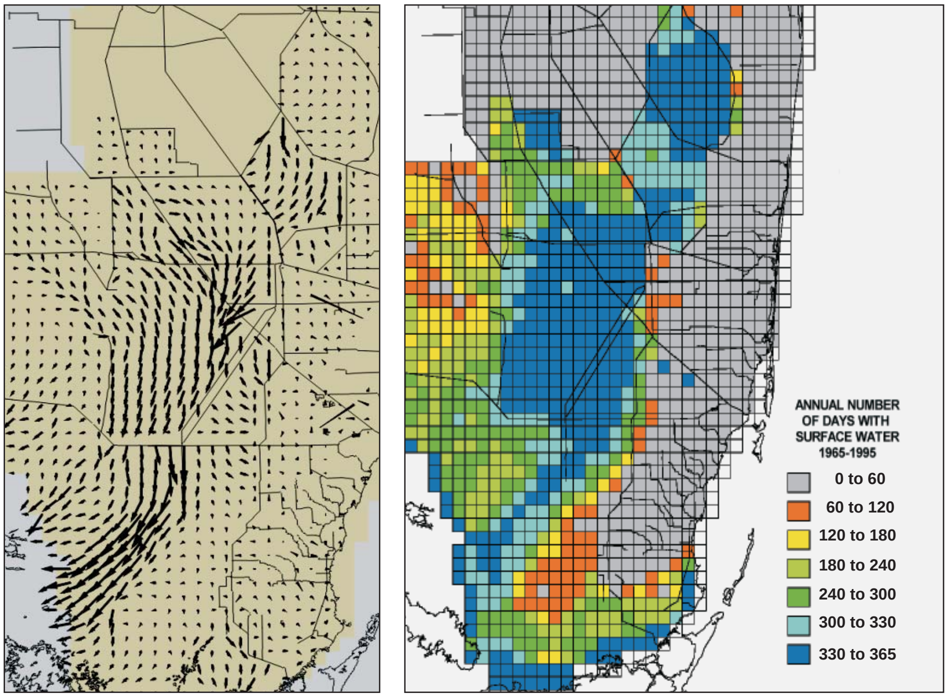
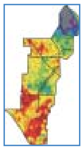


FIGURE 40. Average annual number of days of surface water innundation 1965-1995 (right) and overland flow vectors (left). Figures are from South Florida Water Management District. Note the diminished flow and drying in northern WCA 3A. This drier portion of the Everglades is susceptible to soil oxidation and fire.

Figure 41. Interstate 75 (Alligator Alley) at the eastern edge of the Everglades looking westward. Northern WCA 3A is to the right.

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 60 years. Surface water inundation has been reduced, and consequently soils have subsided and become less organic (Figures 37-40), due to increased biochemical oxidation and more frequent wildfires.



NUTRIENT CONDITIONS

BACKGROUND

Interior Everglades marshes removed from anthropogenic nutrient sources have extremely low total phosphorus (TP) concentrations in surface water. For WY2005 (May 1, 2004 to April 30, 2005) annual median TP concentrations at fixed stations within the Park were as low as the method detection limit of 2 parts per billion (ppb).(71) Historically, the Everglades ecosystem was very nutrient poor, with surface water phosphorus concentrations less than 10 ppb.(72, 119) 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 naturally nutrient-poor condition resulted in a unique mosaic of habitats, such as wet prairies, sloughs, and sawgrass marshes, that included well-developed periphyton communities.

Today, the canal system is a conduit for nutrient transport. Nutrient loading in stormwater from the EAA and urban areas has significantly increased phosphorus concentrations in the downstream Water Conservation Areas, 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 the wet prairie-sawgrass mosaic to dense single-species stands of cattail with no open water, and consequent loss of wading bird foraging habitat. These collective changes impact the structure and function of the aquatic ecosystem.(72,73) By about 1990 over 40,000 acres of the Everglades were estimated to be impacted.(74)

In 2005 Florida adopted a 10 ppb water quality criterion for TP in the Everglades Protection Area (EPA, Figure 42).(75) The objective of the criterion is to prevent nutrient-induced imbalances in natural populations of aquatic flora or fauna. The criterion is applied as a long-term average, with achievement of the criterion within the Everglades waterbody determined by data collected monthly at fixed long-term marsh sampling locations. Compliance is determined by a 4-part test specifying that: 1) the five year geometric mean averaged across all stations is less than or equal to 10 ppb; 2) the annual geometric mean averaged across stations is less than or equal to 10 ppb for three of five years; 3) the annual geometric mean averaged across all stations is less than or equal to 11 ppb; and 4) the annual geometric mean at all individual stations is less than or equal to 15 ppb. Each of the four parts must be met to achieve the criterion. The test is intended to simultaneously allow for the natural temporal and spatial variability that is observed at marsh reference sites, to be sensitive enough to detect long-term increases in TP above 10 ppb, and to place an upper limit on phosphorus at individual marsh locations. The test is applied separately, but in the same manner, at impacted and unimpacted stations, with impacted areas defined as those where the total phosphorus concentration in the upper 10 centimeters of the soil is greater than 500 mg/kg. For the Park, compliance with the criterion is determined not by the 4-part test at marsh stations but rather by P concentration requirements at Park inflow structures. Since R-EMAP data are not collected monthly at fixed sample sites, it is not appropriate to apply Florida's 4-part test to R-EMAP marsh data. However, because of R-EMAP's probability-based design, statements about the area of the marsh that exceed 10 ppb can be made for individual R-EMAP sampling events.

The Park and Refuge have an additional level of water quality protection because they have been designated by Florida as Outstanding Florida Waters (OFW). This anti-degradation designation requires that the quality of water that existed the year prior to March 1, 1979 must be maintained. This stricter OFW designation has been interpreted to require a long-term average TP concentration of 7 ppb at a network of 14 interior marsh stations in the Refuge, and a long-term average of 8 ppb at inflows to the Park at Shark Slough and 6 ppb at inflows to Taylor Slough.(76,77,78) In addition, CERP has adopted the following performance measure for surface water phosphorus: The TP concentration is not to exceed 10 ppb for both the annual geometric mean at marsh stations and the flow-weighted annual geometric mean at water control structures, and should not exceed OFW concentration levels.(8)

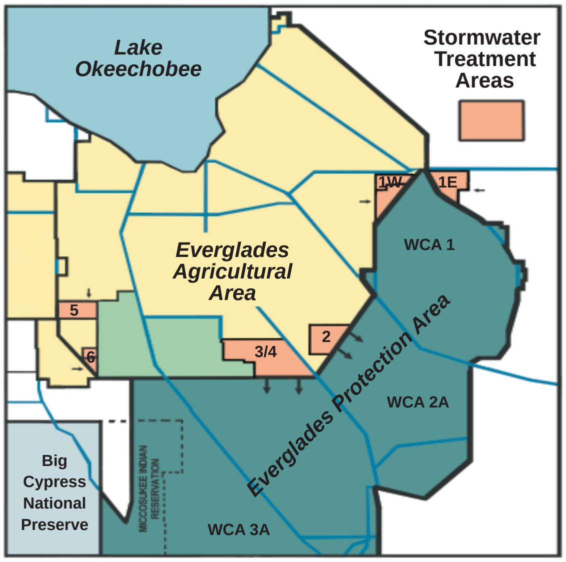


FIGURE 42. Location of phosphorus control program stormwater treatment wetlands. In combination with agricultural best management practices they are to decrease phosphorus to about 10 ppb prior to discharge into the EPA such that the 10 ppb TP criterion is met throughout the waterbody (adapted from SFWMD).

A phosphorus control program was initiated in the 1990s in order to prevent further loss of Everglades plant communities and wildlife habitat due to phosphorus enrichment. The initial phase of this unprecedented program required that discharges from the EAA into the Everglades be at 50 ppb TP or less. Control is to be achieved by a combination of about 47,000 acres of constructed treatment wetlands within the EAA (the Everglades Construction Project), referred to as Stormwater Treatment Areas (STAs) (Figure 42), and agricultural Best Management Practices (BMPs). Agricultural BMPs were required to be in place by 1995. The 1993 to 1996 R-EMAP Phase I sampling period 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. Full BMP implementation began in 1996 with a 25% TP load reduction required. From 1996 to 2006 the BMP program resulted in greater than a 50% TP load reduction from the EAA basin to the Everglades Protection Area, as compared to the load that would have been expected without BMPs. Post-BMP TP concentrations for WY2006 were 119 ppb, with a 44% load reduction.[(48)]

The first STA (3700 acres or about 9% of the initial treatment acreage) began discharging in 1994. There are presently six EAA STAs that have been constructed by the South Florida Water Management District and the Army Corps of Engineers, with a WY2006 effective treatment area of about 32,980 acres.[(48)] If all six EAA STAs and their treatment cells are fully operational, the effective treatment area of the 47,000 acres will be 41,261 acres. These STAs are in addition to the 36,000 acres of proposed CERP constructed wetlands mentioned previously. Flow-weighted annual mean TP inflow to the STAs for WY2006 varied from 104 ppb for STA-6 to 213 ppb for STA-1W, with an average inflow for all STAs of 144 ppb. STA outflow concentrations ranged from 21 ppb for STA 2 to 146 ppb for STA 1E, with an average outflow across all STAs of 44 ppb. The overall load reduction for the STAs was 69%. The cumulative amount of phosphorus retained from 1994 to 2006 was about 810,000 kg.[(48)]

Florida has developed a comprehensive long-term plan for achieving water quality goals for all basins that discharge into the Everglades.[(133)] Such an effort to treat large volumes of stormwater down to 10 ppb TP is unprecedented. The plan recognizes that additional control measures will be necessary to ensure that all discharges to the EPA meet water quality standards. Florida is proceeding with 18,000 acres of additional STAs within the EAA. The long-term plan also addresses the basins other than the EAA with various source controls and capital improvement projects.

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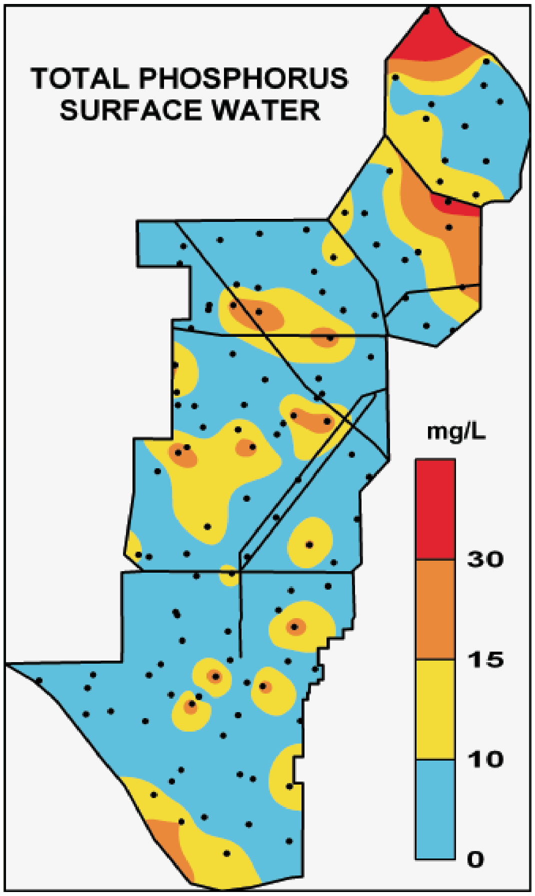


FIGURE 43. Surface water total phosphorus concentration (ug/L) during November 2005.

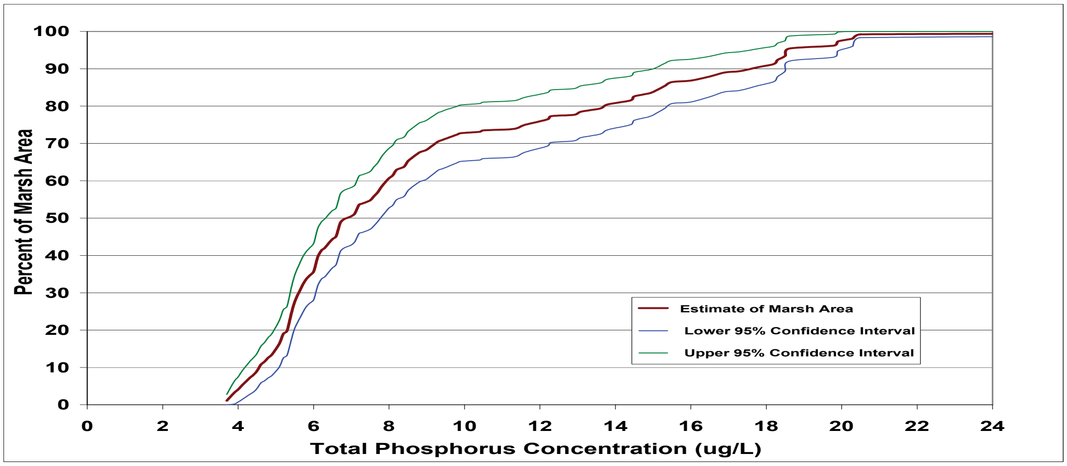


Figure 44. Surface water total phosphorus estimates of marsh area during November 2005.

WATER PHOSPHORUS

R-EMAP Program water and soil samples were analyzed for phosphorus and other indicators of nutrient enrichment, such as nitrogen, chlorophyll a, and alkaline phosphatase activity (Appendix I). The kind of plant communities and the presence or absence of periphyton was noted at each station to enable statistical analysis of relationships between nutrient enrichment and habitat in the Everglades ecosystem. The Program previously documented that canal TP concentrations exhibit strong north to south gradients due to stormwater pumping, with the highest TP concentrations in canals in the EAA during the wet season (median of 149 ppb).(10) During the 1993-1994 wet season about 80% of the canal miles in the EAA had TP concentrations greater than the initial TP control target of 50 ppb, and overall 44% of Everglades canal miles had water TP concentrations greater than 50 ppb.(10)

The spatial pattern of TP during the November 2005 sampling event is depicted in Figure 43. At that time 27.2 ± 7.5% of the marsh had a TP concentration exceeding 10 ppb (Figure 44). This proportion contrasts strongly with 57.8 ± 7.8% during the September 1995 sampling event. TP data from selected fixed stations for WY2006 in the Everglades system are

	INFLOW	OUTFLOW	INTERIOR
EAA BMPs	-	119	-
STAs	144	44	-
Refuge	67	-	15
WCA 2	27	-	18
WCA 3	24	-	10
Park	10	-	6

Table 3. Water total phosphorus concentrations from selected fixed stations in the Everglades for WY2006 (ppb).(48,89,118)

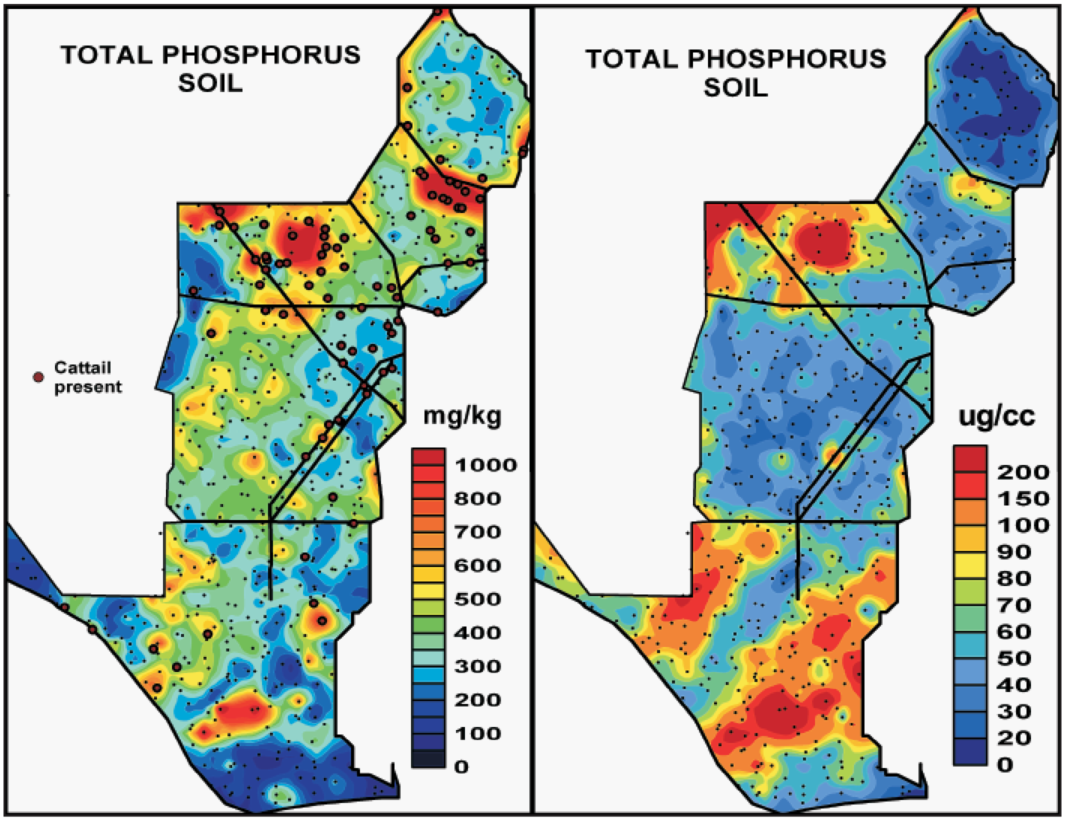


Figure 45. Program data for total phosphorus in soil as milligrams phosphorus per kilogram of soil (left) and as micrograms phosphorus per cubic centimeter of soil (right).

summarized in Table 3. The right column shows the range of values obtained for the interior parts of the major sub-areas. This range occurs over slightly more than half (35% to 90%) of the cdf curve for November 2005 (Figure 44), suggesting good correspondence between R-EMAP data and other measurements.

Soil Phosphorus

Phosphorus in marsh soils can be an indicator of pollution. Previous investigators working in portions of the Everglades with peat soils have documented the association of increasing soil TP with cattail encroachment. Accordingly, elevated soil TP concentrations have been used as indicators of enrichment: 700 mg/kg(79) ; 610 mg/ kg(80); and 600 mg/ kg.(20,81) Florida's Everglades total phosphorus criterion rule specifies a definition of impacted as being where soil TP exceeds 500 milligrams TP per kilogram of soil. CERP has a restoration goal of decreasing the areal extent of the Everglades with soil TP > 500 mg/kg, along with maintaining or reducing long-term average concentrations to 400 mg/kg or less.(8)

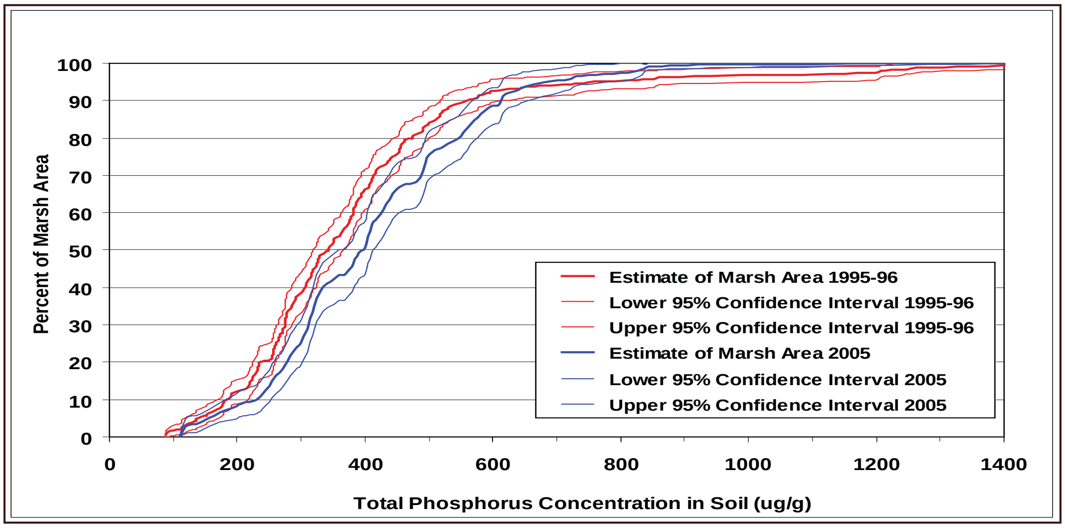


FIGURE 46. Soil total phosphorus estimates of marsh area wet seasons 1995-96 and 2005. About 25% of the Everglades had soil TP exceeding 500 mg/kg in 2005, as compared to 16% in 1995-96.

Soil phosphorus is expressed in Figure 45 (left) on a mass basis as milligrams of phosphorus per kilogram of soil. Results reported here are similar to those obtained by others in 2003 for the EPA.(82,83,84) Program data indicate that in 2005 the area of the Everglades with soil TP concentrations exceeding 500 mg/kg was 24.5 ± 6.4%, while 49.3 ± 7.1% of the 2063 square miles sampled exceeded 400 mg/kg (Figures 45 and 46). This contrasts with 16.3 ± 4.1% exceeding 500 mg/kg in 1995-96, and 33.7 ± 5.4% exceeding 400 mg/kg. Figure 47 shows the most recent (2003-2005) soil TP data at 1270 locations from all of the programs sampling in the Everglades (R-EMAP, University of Florida – SFWMD, and Florida or federal permit transect monitoring). Depicted as mg/kg, WCA 3A north of Alligator Alley, northern WCA 2A, and the edges of the Refuge most proximate to canals have the highest soil phosphorus in the portion of the Everglades underlain by peat soil (Figure 47). There are also several locations throughout southern WCA 3A and the Park with soil TP in excess of 500 mg/kg. However, these locations

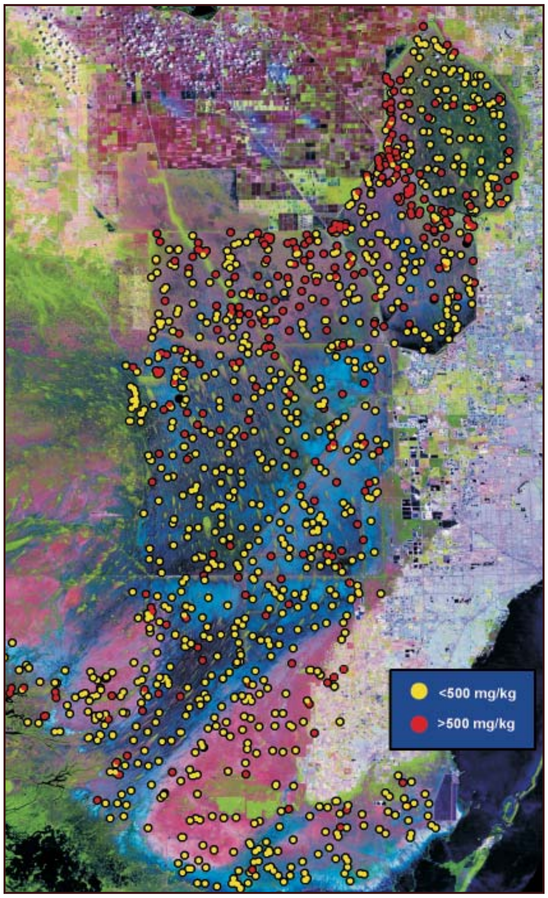


FIGURE 47. Soil total phosphorus for 2003-2005 at 1270 locations from all sampling programs. Red dots indicate soil TP > 500 mg/kg. Data are from SFWMD, FDEP and USEPA.

have no corroborative second indicator of enrichment such as water TP exceeding 10 ppb, presence of cattail, or altered periphyton communities. These specific higher soil TP concentrations are likely reflective of differing soil types and do not indicate nutrient enrichment. USEPA has noted that soil TP concentrations in the 300-600 mg/kg range may not be an appropriate indicator of enrichment for mineral soils within the Everglades.**(85)**

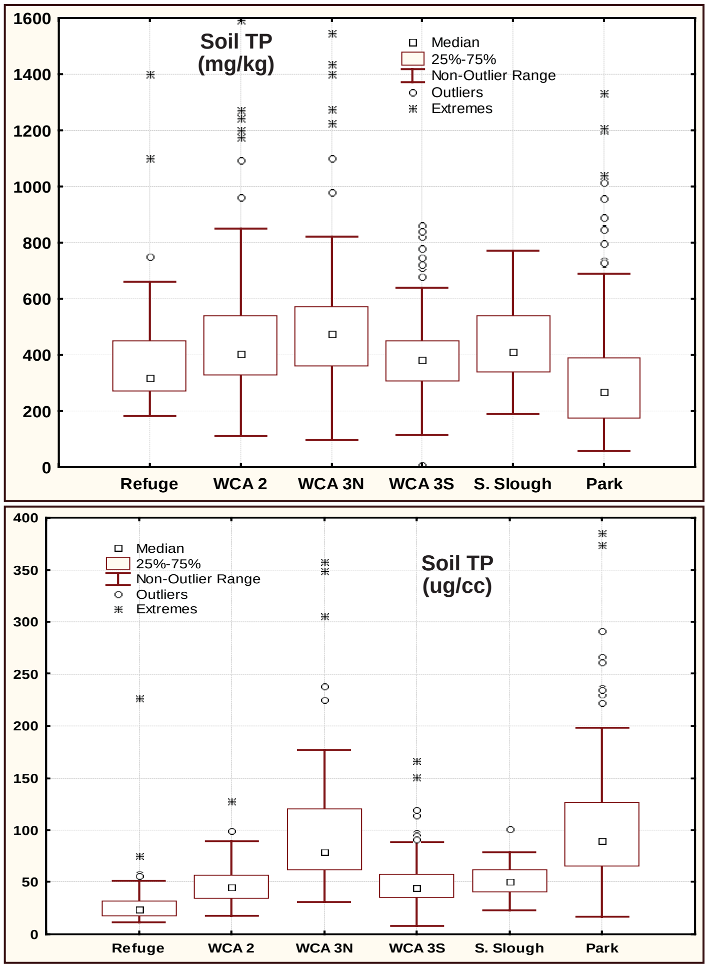


FIGURE 48. Soil total phosphorus concentration by sub-area as mg/kg (top) and ug/cc (bottom).

Testing for statistical differences across Program sample years systemwide indicates that the 2005 wet season soil TP was higher than the 1995-96 wet season (median of 390 mg/kg versus 343 mg/kg). Others have also documented increases in Everglades soil TP in recent years. A spatial expansion of elevated soil TP within WCA 2A was documented from 1990 to 1998, such that the WCA 2A median changed from 516 mg/kg to 860 mg/kg over this seven-year period.**(86)** Analysis of soil TP data within WCA 3A collected from 1992 and 2003 indicate that the area with soil TP > 500 mg/kg increased from about 21% to 30% over these 11 years.**(83)** Additionally, transect sampling along TP gradients in the Refuge and WCA 2A in 1989 and 1999 indicated expansion of the area with soil TP > 700 mg/kg.**(79)**

The 10 ppb long-term geometric mean water quality criterion for TP that applies throughout the EPA has been calculated to translate into an equivalent annual flow-weighted concentration of about 16 ppb at discharges into the Everglades.**(87,88)** This flow-weighted limit has not been formally adopted. However, it is useful to calculate the amount of recent phosphorus loading into the Refuge and WCAs 1, 2 and 3 that is in excess of this flow-weighted concentration. For example, during WY2006 about 169,200 kg (169.2 metric tons, or mt) of TP was discharged into the EPA excluding the Park, which had TP inflows at a flow-weighted mean concentration of only 9 ppb.(data from 89) Had the water discharged into the Refuge and WCAs 2 and 3 been at a flow-weighted TP concentration of 16 ppb, this load would have been 42 mt. Therefore, the excess TP load into the Everglades during WY2006 was about 127.2 mt (38.8 mt into the Refuge, 3.6 mt into WCA 2 and 84.8 mt into WCA 3), even though the STAs retained 176.6 mt(48) and the agricultural BMP program is reported to have resulted in the removal of 117 mt prior to discharge of this stormwater into the STAs or the EPA.(118) The excess TP load into the EPA is calculated to be 103.4 mt for WY2005 and 73.5 mt for WY2004.(data from 90,91) Excess TP loads also occurred each year from WY1990 to WY2004. This excess TP is a potential explanation for the recent increases in soil TP within the Everglades Protection Area.

Soil percent organic matter and bulk density vary greatly throughout the Everglades due to differences between organic peat soils and inorganic marl soils. Soil bulk density is low in peat soils (typically < 0.12 g/cc), and high in calcitic or marl soils (median of 0.36 g/cc for Park marl soils, Figures 38 bottom). Soil TP can also be expressed on a volume basis as micrograms TP per cubic centimeter of soil in order to reflect the reality of different Everglades soil types. When soil TP is adjusted for bulk density (Figure 45 right), the locations in southern WCA 3A that were above 500 mg/kg no longer have high phosphorus. Areas in the Park with higher bulk density become distinct, although these areas are known to be oligotrophic. Peat soils with higher TP are generally limited to WCA 2A and the edges of the Refuge. The Refuge interior and portions of the Park have the lowest soil phosphorus. Figure 45 right indicates that WCA 3A south of Alligator Alley does not have high soil TP as ug/cc. These observations are consistent with monthly surface water TP data from fixed marsh stations at these locations which have annual geometric mean TP concentrations <10 ug/L.(72) Testing for statistical differences across Program sample years systemwide indicates that the 2005 wet season soil TP, expressed as ug/cc, was no different than the 1995-96 wet season.

Nitrogen

Nitrogen is another plant nutrient that can contribute to eutrophication. Because the Everglades marsh is phosphorus-limited,(72,73,119) nitrogen has not been a major concern. The water quality criterion for total nitrogen that applies to the Everglades is a narrative: nutrient concentrations shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. CERP has adopted an Everglades restoration goal of less than or equal to the baseline mean during 1994-2004; however, this baseline has not been defined.(8)

Surface water Total Nitrogen (TN) during November 2005 had a distinct spatial gradient, with the highest concentrations above 1.0 mg/L found generally in WCA 2A and at two Refuge stations (Figure 49 left). The overall median and arithmetic mean were both 0.58 mg/L. An average of 86% of the surface water nitrogen was in organic forms. Surface water nitrogen

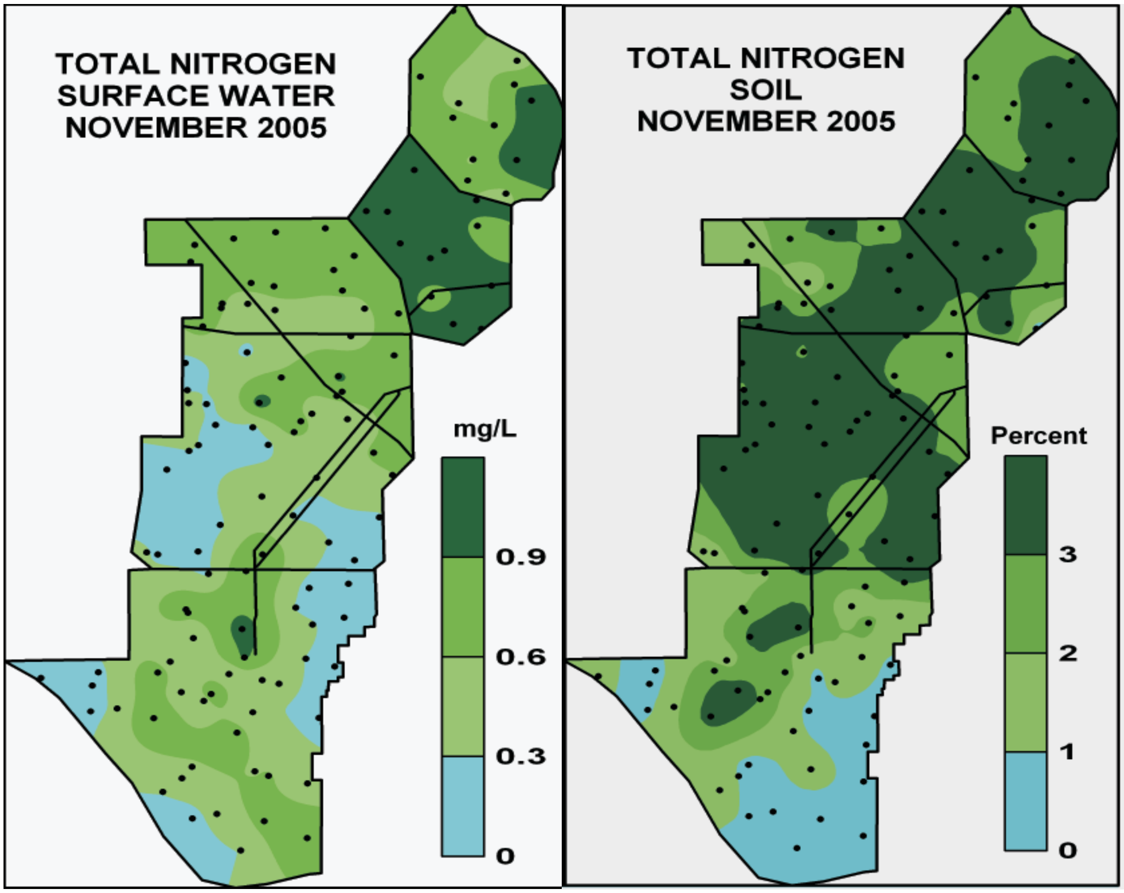


Figure 49. Surface water total nitrogen concentration (left, mg/L) and soil total nitrogen concentration (right, percent) during November 2005.

gradients throughout the Everglades have been previously reported. During 1978-1982 the five-year mean nitrate concentration entering the Park in western Shark Slough was 0.012 mg/L, as compared to 0.938 mg/L at the S-8 structure which discharges stormwater from the EAA.(38) For 1978-1987 the mean TN concentration at pumps discharging stormwater from the EAA were 3.4 to 6.0 mg/L, with inflows to the Park at 2.0 mg/L(114). During water year 2006, total nitrogen concentration varied at water control structures, depending upon proximity to the EAA. The median inflow TN concentration to the Park was 0.99 mg/L, as compared to 2.4 mg/L for the Refuge. The annual median interior concentration in the Park was 1.2 mg/L as compared to 2.4 mg/L for the Refuge.(89)

Nitrogen cycles in water bodies in organic and inorganic forms. Nitrification is the oxidation of ammonium to nitrate, the nitrogen form assimilated by many plant species. Denitrification is the reduction of nitrate to nitrogen gas, which can leave the water body and enter the atmosphere. Although denitrifcation is a potential pathway for nitrogen loss from Everglades surface waters, this pathway is not major. Previous studies have found that only 10% of nitrogen was lost from peat soils to denitrification, 34% was lost from marl soils(92), and the rate of removal increased as soils became more phosphorus-enriched.(92,93)

The organic peat soils of the Everglades have a TN content of about 1% to 4.4%, while the marl soils of the Park generally have a TN content of <1% (Figure 49 right). The peat soils of the EAA, which originated from Everglades sawgrass, are also reported at about 1% to 4%.(94) The major source of agricultural nitrogen in the EAA is the soil itself, with no fertilizer additions of nitrogen necessary for sugarcane and minimal additions necessary for vegetables.(94) Drainage water from the EAA is reported to export TN at rates ranging from 30-46 kg N/hectare/year(94) and 12-40 kg N/hectare/year.(95) During WY2006 the inflows to STAs 1W, 2, 3/4 and 5 had flow-weighted mean TN concentrations of 3.9, 4.0, 3.8 and 1.6 mg/L respectively, while the outflow concentrations averaged 3.0, 2.5, 1.9 and 1.3 mg/L. The STAs removed a minimal to moderate amount of TN, with treatment efficiencies of 19% to 50%.(48) The five-year TN treatment efficiency for STA-1W is reported at 26%, as compared to 79% for TP.(47)

MACROPHYTES and PERIPHYTON

Figure 50. Mosaic of tree islands, sawgrass marsh and wet prairies within Shark Slough, Everglades National Park. The brownish color is the periphyton mat at the water surface in wet prairies. This photo was taken during the wet season when water depths were about 3 feet.

Plant Communities

The Everglades are defined by a unique mosaic of vegetation community types (Figure 50). Wet prairies and open water sloughs devoid of dense emergent macrophytes serve as preferred habitats for foraging wading birds.(96) These areas are also the Everglades wetland type with the greatest diversity of native flora and fauna.(30) Factors driving vegetation community composition include hydroperiod, salinity, nutrients, and disturbances such as fire, frosts, and hurricanes. During 2005 the Program conducted three types of plant analyses at the 228 biogeochemical stations.

Field crews recorded the dominant plant community at each sample point based on visual observation (Figure 51). The dominant community was identified as sawgrass (*Cladium jamaicense*) at 58% of the 228 sites, and the wet prairie-slough complex occurred at 32% of the sites. Wet prairie is prevalent in the Refuge, and in wetter portions of WCA 3. Sawgrass tends to dominate north

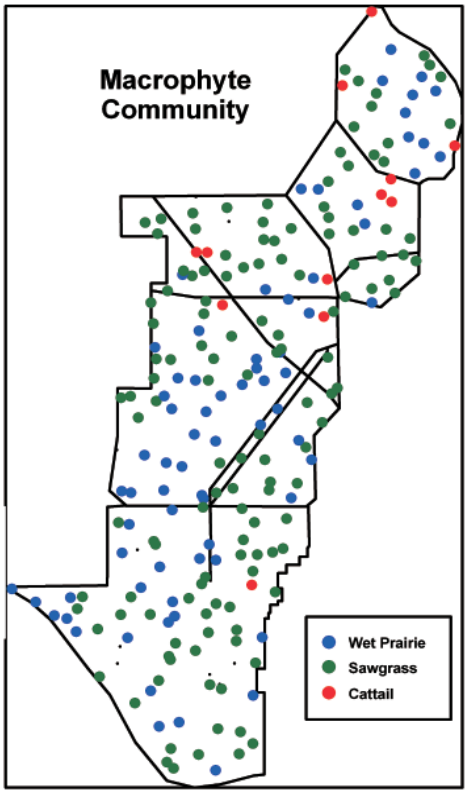


Figure 51. Dominant plant community during 2005.

of Alligator Alley and in WCA 2, while the Park contains a mix of the two communities. The remaining sites were other, minor community types (4%) and cattail (*Typha domingensis*) stands (5%).

Plants were also studied quantitatively on-station in 2005. Program crews recorded macrophyte species frequency in twenty 0.25-square meter quarter-quadrats arranged along 10-meter transects. One random transect associated with the biogeochemical sampling point was established at all 228 stations. At stations where a second community was present within practical distance of the point, a representative transect was established in that type. During the 2005 dry season sampling event 143 plant taxa were found. Cluster analysis of all these data identified three widespread plant associations in the Everglades marsh -- a cluster dominated by sawgrass; a cluster dominated by deeper water species, such as white water lily (*Nymphaea odorata*) and various bladderworts (*Utricularia spp*); and a cluster dominated by spikerush (*E. cellulosa*) and purple bladderwort (*U. purpurea*). These latter two clusters are refered to in this report as wet prairie-slough communities. Six invasive, exotic species (not native to North America) were also documented -- melaleuca (*Melaleuca quinquifolia*), climbing fern (*Lygodium microphyllum*), Brazilian pepper (*Schinus terebinthefolius*), Australian pine (*Casuarina sp.*), salvinia (*Salvinia minima*), and primrose-willow (*Ludwigia peruviana*).(12,97)

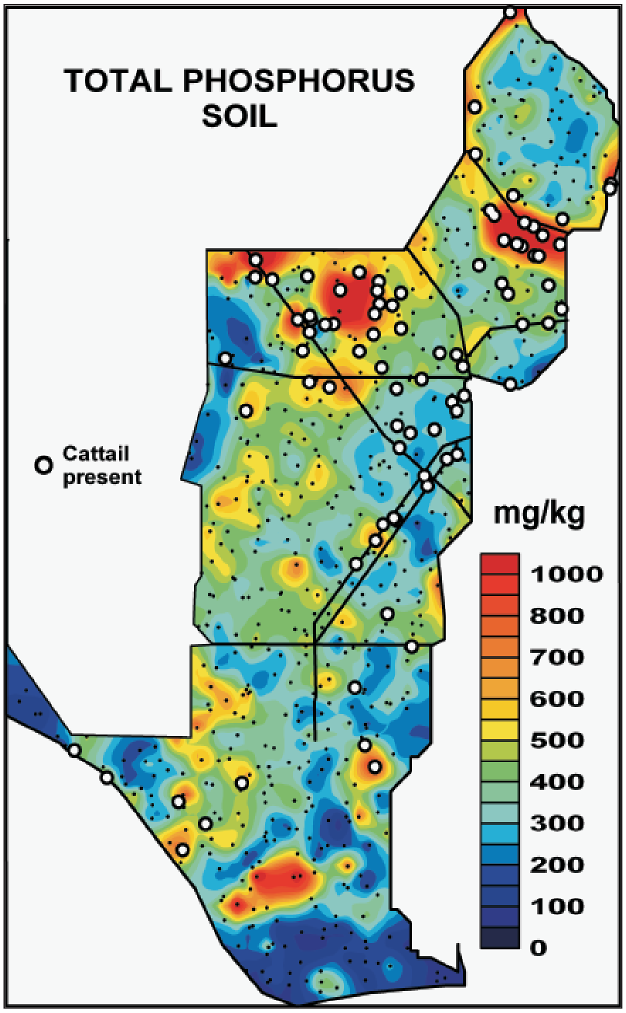


Figure 52. Soil total phosphorus (mg/kg) and cattail presence based on Program data.

Using the same classification system (jointly developed specifically for the Everglades by SFWMD scientists, R-EMAP investigators, and others)(12, 120) that was used on

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

the Phase II (1999) Program stations, 1 square kilometer centered on each 2005 R-EMAP station was mapped digitally. Each station was mapped twice, using aerial photographs taken in 1994-95 and in 2003-04. Change detection analysis of these data is ongoing. Using the imagery from 1994-95, SFWMD recently completed the first classified vegetation map of WCA3.(99) Sawgrass and wet prairie communities accounted for 87.5% of this WCA. Cattail occupied 5% of the Area, with large expanses in the northern part. Building on the work done for Phase II, the R-EMAP sample maps will be compared to the entire WCA3 map, to demonstrate the feasibility of inferring change over wide areas based only on sampling at the 1 square kilometer scale.

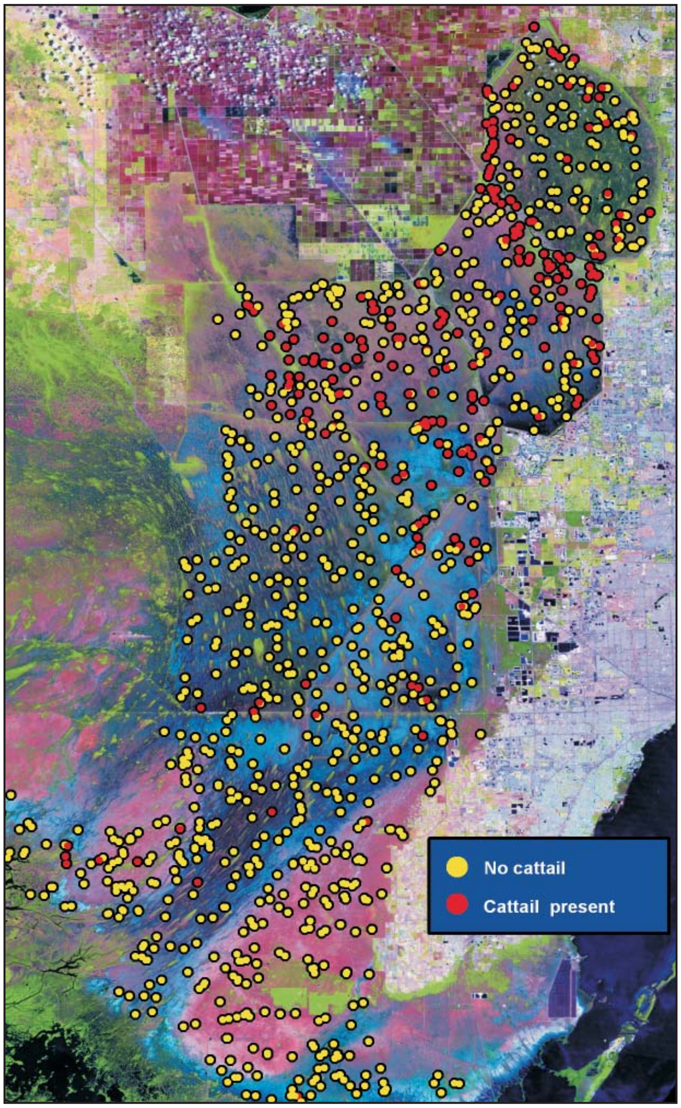


FIGURE 53. Presence or absence of cattail during 2003 - 2005 at 1270 Everglades stations sampled by all programs. Red dots indicate cattail was present. Data are from SFWMD, FDEP and USEPA.

Cattail is a native species known to respond to phosphorus enrichment such that it can replace wet prairies and sawgrass. Conversion of wet prairies to dense cattail constitutes a loss of the prefered foraging habitat for wading birds.(98) There is a strong association between the presence of this invasive species and elevated soil phosphorus or proximity to canals. Cattail was commonly encountered in the northern portions of WCA 3A (attributed to drying conditions and soil mineralization) and

WCA 2A (attributed to enrichment from stormwater), and at sites that were close to canals. Cattail presence throughout the EPA was also documented during 2003 for the SFWMD soil phosphorus sampling project. Figure 53 shows the presence or absence of cattail at the 2003 SWFMD and 2005 R-EMAP stations combined (1270 locations). The expanse of cattail in northern WCA3 is evident, as it is in peripheral portions of the Refuge and WCA 2. Based on the transect quadrat data, cattail was documented as being present, but not necessarily dominant, at 19% of the R-EMAP sites sampled in 2005. Comparable data are not available for earlier phases of the Program due to refinement of methods.

FIGURE 54. Epiphytic periphyton (bottom) formerly surrounding an *Eleocharis* stem (top).

PERIPHYTON

Well-developed attached or floating calcareous periphyton mats are a defining characteristic of the hard water Everglades, particularly wet prairies and deeper slough areas (cover and

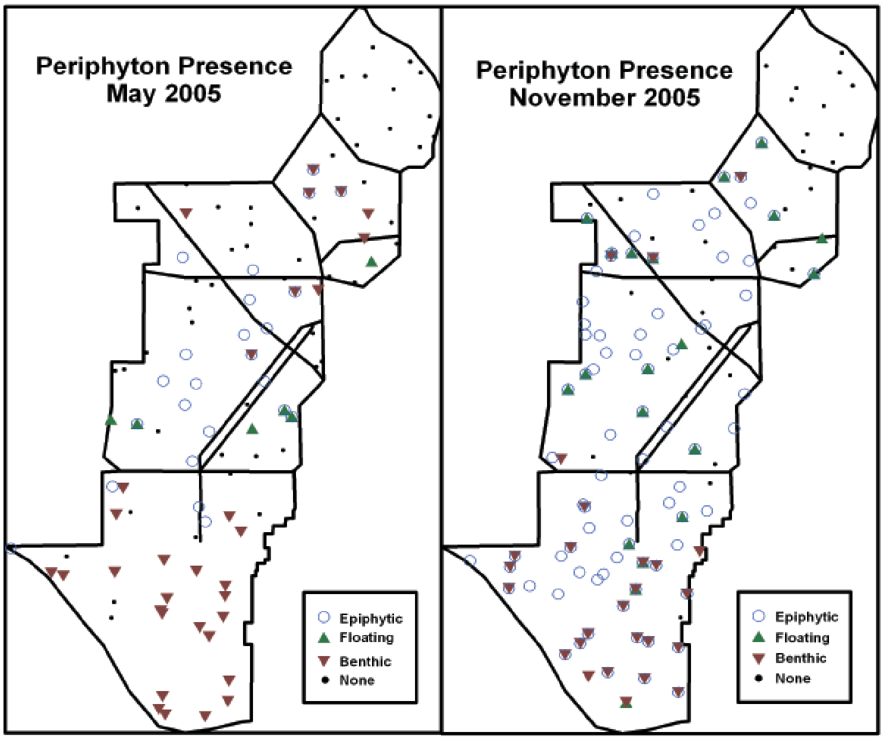


FIGURE 55. Presence of epiphytic, floating and benthic periphyton during 2005.

Figure 56. Well-developed periphyton community at short-hyrdroperiod marsh within the Park. Floating and epiphytic forms are visible.

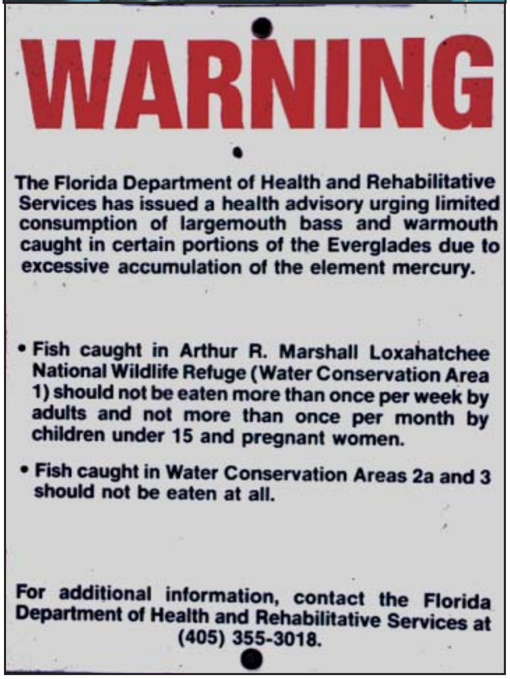
Figures 54 & 56). These conspicuous microscopic plants serve multiple functions such as providing oxygen to the water column for fish, removing calcium carbonate from the water and depositing it as soil, removing phosphorus from the water to very low concentrations, and serving as the base of the local food web.(72) Hydroperiod and water depth, water ions, and phosphorus concentration all affect periphyton extent and structure.(131) Periphyton communities are sensitive to very slight increases in nutrient concentrations, with increases in phosphorus causing changes to the periphyton assemblage, including species composition and biomass, or even the disappearance of the entire mat. Consequently, periphyton are a sensitive and important indicator of marsh ecosystem status.(73,100)

Periphyton mats were found at 63% of the 228 sample sites during 2005, as compared to 67% of the sites during 1995-1996. The species composition of 2005 periphyton will be documented in companion reports. During 2005 three types of periphyton growth forms were sampled: benthic mats which are at the sediment surface (Figure 36 bottom), epiphytic mats which are attached to emergent macrophytes (cover and Figure 54), and floating mats that are distinct from macrophytes (Figure 56). The most common form of periphyton was epiphytic, which was observed at 103 or 45 % of the stations (Figure 55), followed by benthic (25%) and floating (11%). Benthic mats were most common in the marl, short-hydroperiod portions of the Park. There were no periphyton mats encountered in the soft water Refuge, the eutrophic portion of WCA 2A, and parts of northern WCA 3A. With the exception of the Refuge, the areas where periphyton mats were not found tend to be areas where wet prairies are absent and dense 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.(101) 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 and not mat-forming.(73)

MERCURY CONTAMINATION

Since about 1990 mercury contamination has been a concern in the Everglades. Elevated mercury in gamefish caused Florida to issue fish consumption advisories to protect human health. These advisories either ban or restrict consumption of nine species of gamefish from over two million acres encompassing the Everglades (Figure 57). There is a ban on consumption of largemouth bass longer than 14 inches.(102) The existence of these advisories means that the Everglades waterbody does not meet the “fishable” portion of its designated use. In addition, ecological risk assessments and mercury dosing studies have indicated that populations of top predators in the Everglades could be adversely affected by mercury contamination, such that mercury accumulation through the food web may reduce the health or breeding success of wading birds(28,103,116,117) and the Florida panther.(104)

Florida’s class III surface water criterion for total mercury is 12.0 nanograms per liter (ng/L or parts per trillion). Since 1995, 733 different locations within the EPA have been sampled by Program personnel for total mercury in surface water. The overall median of those data is 2.0 ng/L, as it was for the November 2005 sampling (Figures 58 and 64). Only 6 of 733 samples exceeded the 12.0 ng/L surface water criterion. These 6 samples were all collected during the dry season at shallow marsh sites (water depths from 0.1 to 0.7 feet). During 2005 the highest concentrations occured in the northern Everglades (Figure 64). Statistical testing for differences across sampling phases within season indicates that there was a very slight, but significant ($p<0.05$), increase in surface water total mercury during the wet season in 2005 as compared to 1995. Dry season concentrations were higher than



WARNING

The Florida Department of Health and Rehabilitative Services has issued a health advisory urging limited consumption of largemouth bass and warmouth caught in certain portions of the Everglades due to excessive accumulation of the element mercury.

- Fish caught in Arthur R. Marshall Loxahatchee National Wildlife Refuge (Water Conservation Area 1) should not be eaten more than once per week by adults and not more than once per month by children under 15 and pregnant women.
- Fish caught in Water Conservation Areas 2a and 3 should not be eaten at all.

For additional information, contact the Florida Department of Health and Rehabilitative Services at (405) 355-3018.

Figure 57. Young fisherman at the Refuge boat ramp (top); fish consumption advisory to protect human health at the same boat ramp (bottom).

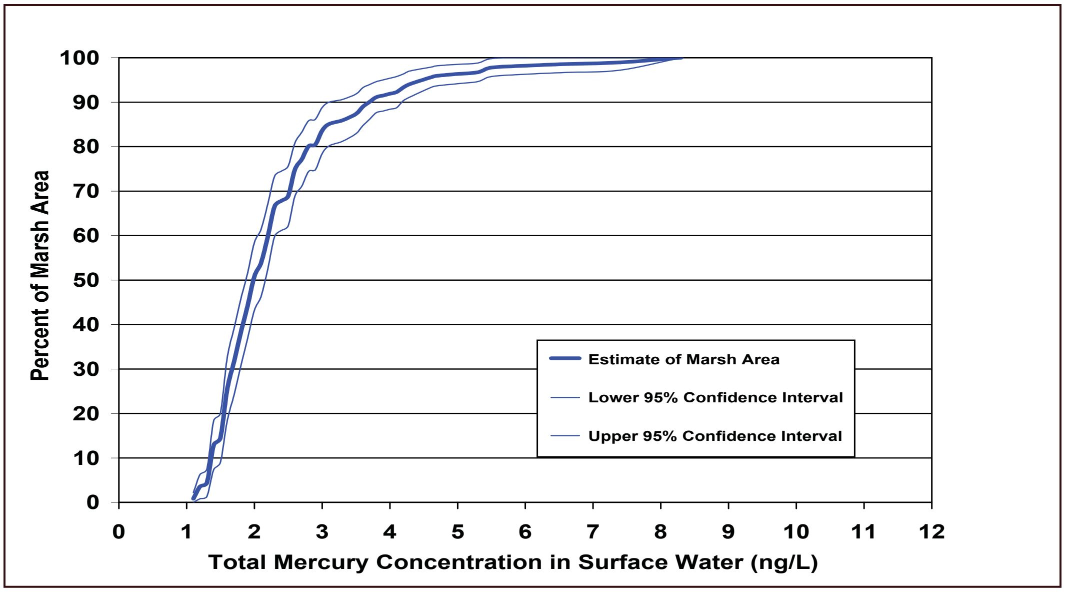


FIGURE 58. Estimates of marsh area for wet season total mercury concentration in surface water during November 2005.

wet season concentrations. Bioaccumulation of mercury to unacceptable levels in gamefish is occurring although the 12 ng/L surface water criterion is being met.

Elemental mercury deposited into surface water from the atmosphere can be converted to methylmercury (MeHg) by bacteria in the presence of sulfate and organic carbon.(56,64) Methylmercury is the toxic form of mercury that bio-accumulates and biomagnifies in the aquatic food chain. There are no numeric water quality standards for methylmercury in surface water. However, Florida water quality standards require that there shall be no substances in concentrations which injure, are chronically toxic to, or produce adverse physiological or behavioral response in humans, plants or animals.(123) Numerous factors affect the bioaccumulation of mercury in aquatic life.(113) Some of these factors include the length of the aquatic food chain, soil type, pH, and dissolved organic material.(105) In the Everglades during the last decade about 30 factors have been suggested by various scientists as playing a role in mercury bioaccumulation. Interrelationships among the factors are poorly understood and may be waterbody specific. Because of these complexities, USEPA recently concluded that in order to protect human health it is more appropriate to have a fish tissue residue water quality criterion for methylmercury rather than a water column-based water quality criterion. The resulting methylmercury water quality criterion recommended by USEPA is a fish tissue residue criterion of less than 300 ug/kg.(105) About 95–99 % of the mercury that is found in top predator tissue is in the methyl form.(106)

A 2007 status report from the Everglades mercury program states that(24):

- 71% of the largemouth bass sampled in the WCAs in 2005 exceeded the recommended fish tissue criterion of 300 ug/kg, while 100% of the largemouth bass from Shark Slough in the Park exceeded this criterion;
- mercury dropped in bass in the WCAs from a median of about 1500 ug/kg in 1991 to about 300 ug/kg in 2001 but then increased to about 500 ug/kg in 2005. However mercury has simultaneously increased in bass in portions of the Park, where during 2005 the median was about 1200 ug/kg;
- mercury concentrations in wading bird feathers have declined since 1998, except for in the Park;
- there was no trend in wet deposition of mercury from 1994 to 2005 in the Park.

Mosquitofish have been sampled for the duration of the Program. This species is an ideal indicator of mercury contamination for several reasons: They are the most abundant fish in the Everglades and they are found throughout the canals and in all marsh habitats(110); they are easily sampled; they are in the food web for gamefish and wading birds, so they provide insights that are relevant to both ecological health and human health; and, their average lifespan is several months and they have a small home range, so they integrate mercury exposure over a short time frame in a discrete area. During the four wet season sampling events conducted by the Program, mosquitofish have been successfully collected at 96% of the 414 Everglades marsh sites, including wet prairie, sawgrass and cattail habitats. Everglades mosquitofish are a secondary consumer and have been reported to be at trophic level 2.0 to 3.0(115) and 4.0 to 4.5.(107) Everglades mosquitofish consume animal prey (crustaceans, insects, arachnids), algae, detritus and plant matter.(115)

During 1995-1996 the Program documented a pronounced spatial gradient in mosquitofish mercury, with the highest concentrations in remote portions of WCA3A and extending into Shark Slough in the Park.(9,12,13) This same spatial pattern, with the highest concentrations in WCA 3 and the Park, was documented again in 2005 (Figures 59 and 62). These results are consistent with those for other biota that indicate the highest mercury concentrations in the Everglades occur in the Park or WCA 3 for largemouth bass,(24) great egrets,(24) and alligators.(26) A recent risk assessment on the effects of methylmercury on great egrets concluded that birds foraging in the Park have a high probability of exceeding the acceptable daily mercury dose level and cumulative dose level necessary to protect nestlings and pre-nesting females. There is also a high probability of exceeding the lowest adverse effects level.(105)

The United States Fish and Wildlife Service has recommended a level of 100 ug/kg

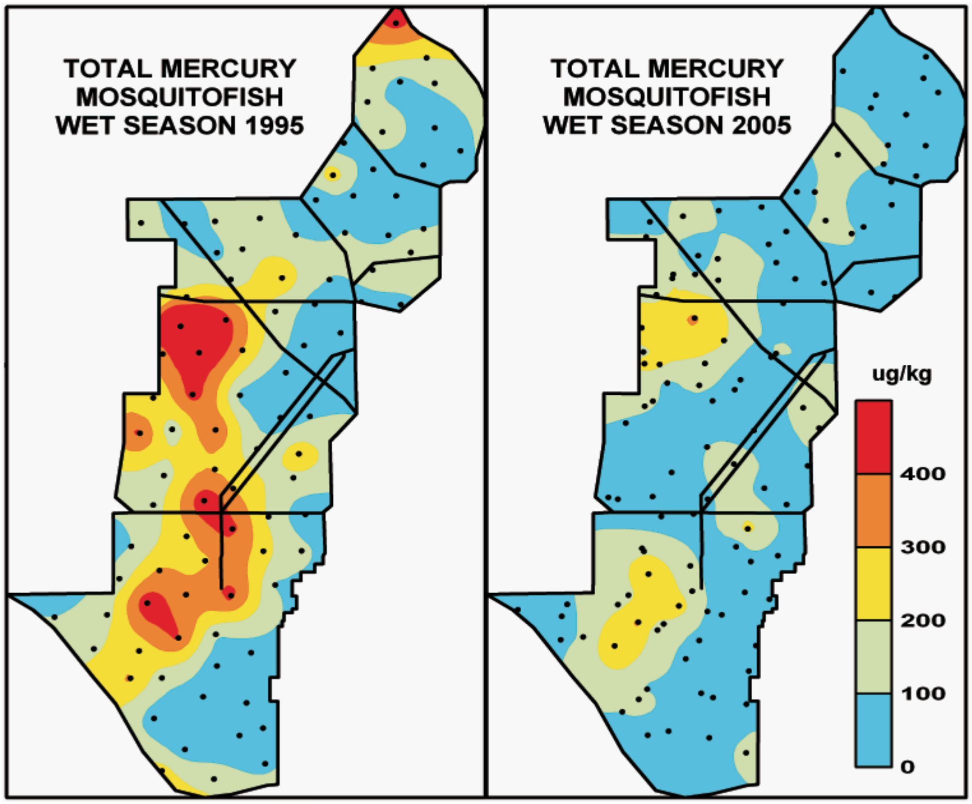


FIGURE 59. Mosquitofish mercury during wet season sampling 1995 and 2005.

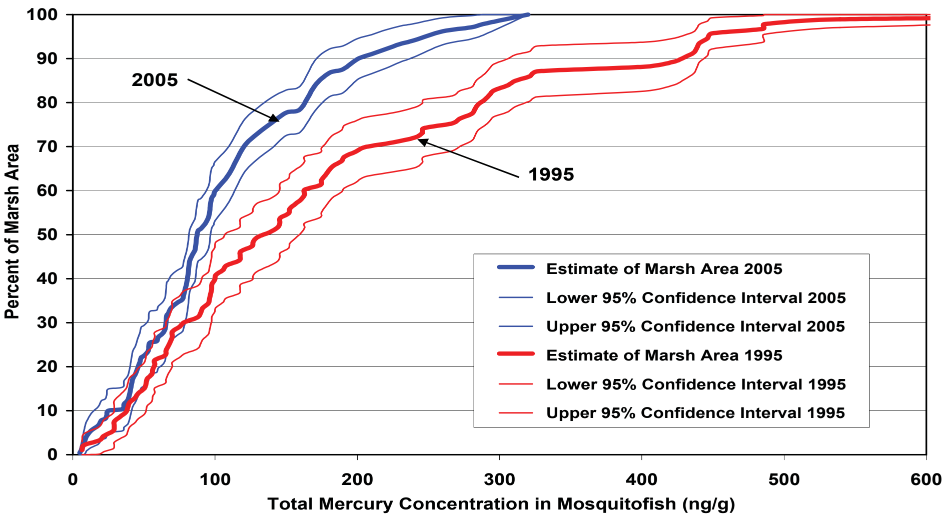


FIGURE 60. Mosquitofish mercury concentration estimates of marsh area during September 1995 and November 2005.

(micrograms per kilogram, or parts per billion) in prey fish in order to protect top predators such as wading birds from mercury contamination.(108) During the 2005 wet season sampling, 40.1 (± 6.7) % of the marsh had mosquitofish mercury concentrations that exceeded 100 ug/kg (Figure 60). This proportion is in contrast to the 59.9 (± 7.3) % found during the 1995 wet season sampling. USEPA has recommended a concentration of 77 ug/kg at trophic level

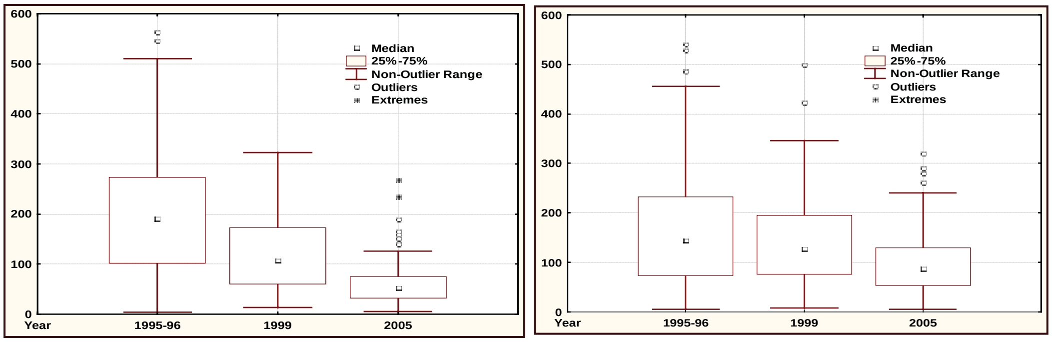


Figure 61. Box and whisker plots of mosquitofish mercury concentration (ug/kg) throughout the Everglades by Program phases during the dry season sampling (left) and wet season sampling (right).

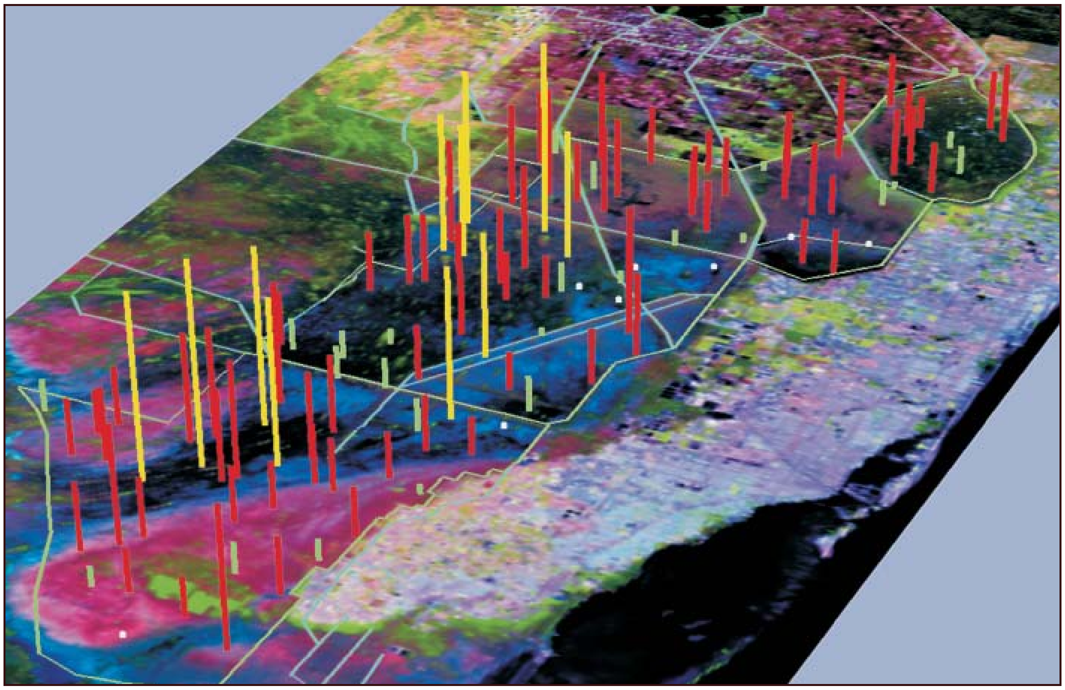


Figure 62. Mosquitofish mercury during November 2005. Yellow bars are concentrations > 200 ppb, red bars are >50 ppb and < 200 ppb, light green are < 50 ppb, white dots indicate that field crews were unsuccessful in efforts to collect fish.

3 for protection of birds and mammals.(109) During the 2005 wet season sampling, 64.7 (± 7.3) % of the marsh had mosquitofish mercury concentrations that exceeded 77 ug/kg. This proportion is in contrast to 70.5 (± 7.1) % found during the 1995 wet season sampling.

Statistical testing for differences between cdf curves indicates that during the dry season and the wet season there was a significant and pronounced drop in mosquitofish mercury concentration from 1995 to 1999 (wet season $p < 0.01$; dry season $p << 0.001$) and again from 1999 to 2005 (wet season $p < 0.01$; dry season $p < 0.01$). This result is consistently supported by krigs (Figure 59), box-and-whisker plots (Figure 61), and the z-test for differences between means. Program data also indicate a significant drop in methylmercury concentration in all forms of periphyton during the dry season throughout the three Program phases. The test for differences between cdf curves for methylmercury in surface water during the 2005 wet season, as compared to 1995-96, indicates a significant ($p<<0.001$) but slight drop (median changed from 0.29 ng/L to 0.21 ng/L).

Program data indicate extremely high bioaccumulation of mercury in Everglades biota. November 2005 median concentrations for total mercury were as follows (Appendix II): surface water, 2.2 parts per trillion; floating periphyton, 15.5 parts per billion (ppb); benthic periphyton, 9.7 ppb; mosquitofish, 87 ppb; floc, 130 ppb; sediment, 140 ppb. Median methylmercury concentrations were: surface water 0.2 parts per trillion, floating periphyton 1.6 ppb; benthic periphyton 0.47 ppb; epiphytic periphyton 1.7 ppb; floc 3.0 ppb; sediment 0.49 ppb.

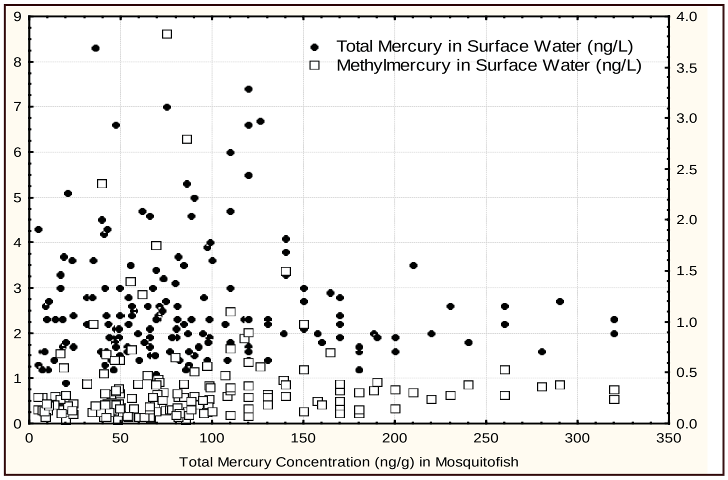


Figure 63. Scatterplot of November 2005 mosquitofish mercury versus surface water methylmercury (right axis) and total mercury (left axis) for the entire study area. Mosquitofish mercury concentration is not correlated with surface water mercury concentration.

The bioaccumulation factor (BAF) is an index that expresses the degree to which mercury accumulates in fish compared to its concentration in surface water.(129, 130) The highest surface water total mercury and methylmercury concentrations occur in WCA 2 and the northern Everglades (Figure 64), while the highest mercury concentrations in mosquitofish occur to the

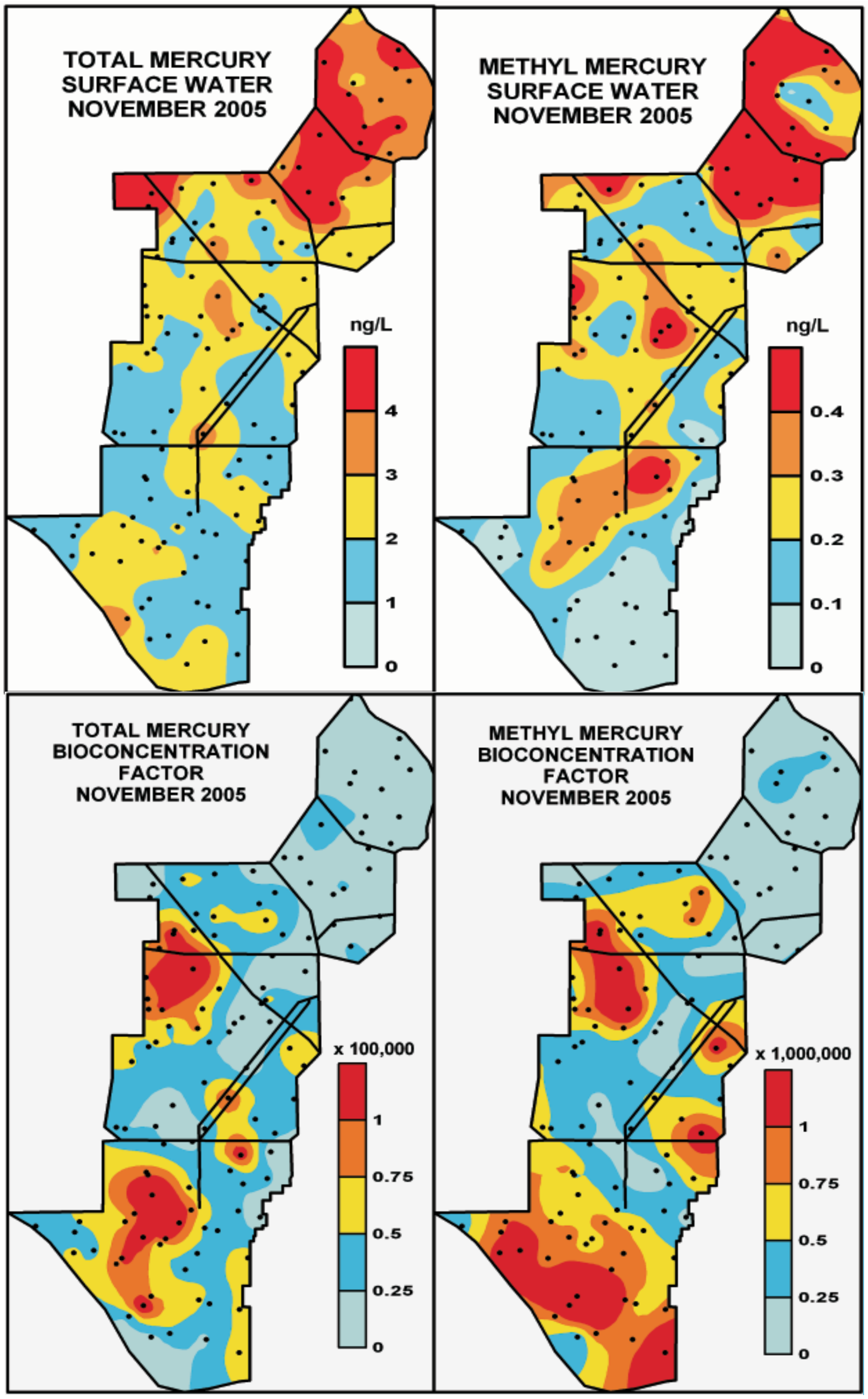


Figure 64. Total mercury concentration in surface water during November 2005 (top left), methyl mercury concentration in surface water (top right), mercury bioconcentration factor from surface water methylmercury to mosquitofish (bottom right) and mercury bioconcentration factor from surface water total mercury to mosquitofish (bottom left).

There has been a sharp decline in mercury concentrations in preyfish from 1995/96 to 1999 to 2005, although concentrations remain too high to protect top carnivores.

south in WCA 3A and the Park (Figure 58). Bioaccumulation factors were calculated as the concentration of mercury in mosquitofish divided by the concentration of methylmercury in surface water (BAFm) (Figure 64 bottom). Bioaccumulation factors were also calculated as the concentration of mercury in mosquitofish divided by the concentration of total mercury in surface water (BAFt). BAF varies in space by a factor of about ten with the highest BAF observed in the areas to the south with the higher concentrations in mosquitofish. The median BAFm was 4.7×10^5 with values as high as 2.1×10^6 in the Park.

Pearson correlation coefficients were calculated for about 50 parameters versus total mercury in fish, and versus BAFs (Appendix III). The parameters most highly correlated with fish mercury were methylmercury in all periphyton forms combined ($r= 0.58$, $p<0.001$), methylmercury in epiphytic periphyton ($r= 0.68$, $p=0.001$) and TP in floc ($r= - 0.58$, $p<0.001$). Floc is non-consolidated biogenic detrital matter (Figures 15 and 65) that is an important food web component for Everglades invertebrates and fish.(111) During November 2005 floc was present at 77% of the sampling sites, with a thickness of up to 39 cm (Figure 65). The strong correlation between mercury in periphyton and mercury in mosquitofish is not surprising given that periphyton are integral to their food web.(107) There was no correlation between fish mercury and surface water total mercury or methylmercury (Figure 63), and there was no correlation between fish mercury and forms of carbon. The fact that the high water column total mercury and methyl mercury in WCA 2 and the Refuge do not result in high mercury in fish may be due to an inhibitory mechanism. Mosquitofish mercury is correlated with DOC-normalized water methylmercury, but not water methylmercury itself.(112) The highest surface water DOC and porewater sulfide concentrations in the EPA are found in WCA 2 (Figures 32 and 33). Sulfide and carbon have been reported to inhibit methylation.(50,63,64) Program data corroborate this finding. The

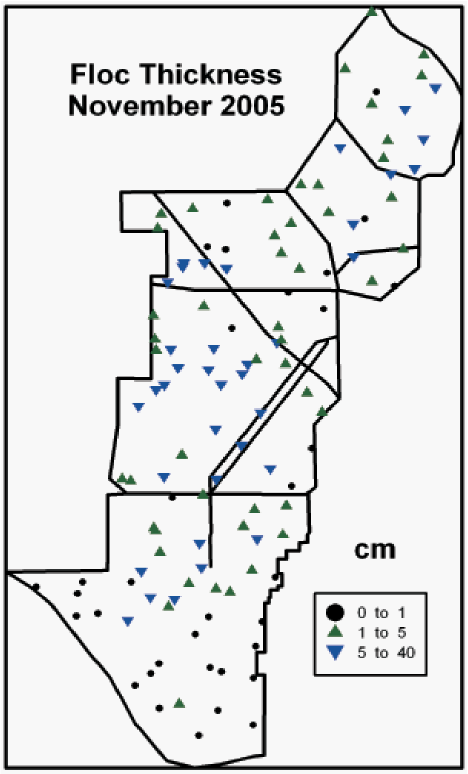


FIGURE 65. Floc thickness during November 2005.

parameters most highly correlated with BAFm were surface water DOC (r= - 0.65, p<0.001), porewater sulfide (r= - 0.63, p<0.001), porewater sulfate (r= - 0.54, p<0.001) and MeHg in floating periphyton (r= - 0.47, p=0.047). The parameters most highly correlated with BAFt were surface water alkaline phosphatase activity (r= 0.57, p<0.001) and floc TP (r= - 0.56, p<0.001).

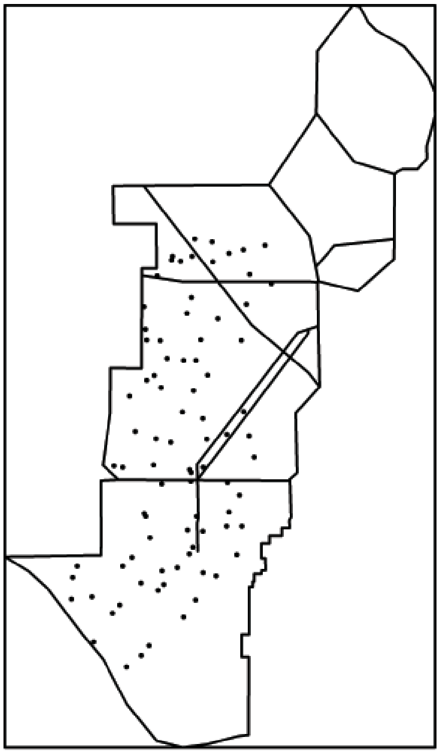


Figure 66. Core area of highest mosquitofish mercury during wet season sampling 1995.

In order to identify constituents relevant to the pronounced drop in mosquitofish mercury observed in Program data from 1995 to 2005, a core area was recognized where the high mercury concentrations in fish occurred in 1995 (Figure 66). Pearson correlation coefficients were recalculated for November 2005 using only stations within this area. The highest correlation coefficients with fish mercury were surface water MeHg (r= 0.47 p<0.001), floc TP (r= - 0.48 p=0.004), sediment MeHg (r= 0.41 p=0.001) and MeHg in epiphytic periphyton (r= 0.42 p=0.002). The parameters most highly correlated with BAFm were MeHg in floating periphyton (r= - 0.94 p<0.001) and water depth (r= - 0.53, p<0.001). The parameter most highly correlated with BAFt was sediment MeHg (r= 0.46 p<0.001). MeHg in surface water was most correlated with MeHg in floating periphyton (r= 0.87 p<0.001) and surface water sulfate (r= 0.65 p<0.001). MeHg in benthic periphyton was highly correlated with surface water sulfate during the wet season (r= 0.87 p<0.001).

The Everglades R-EMAP Program consistently documents conditions throughout the Everglades in a quantitative manner. This documentation provides a basis for determining the effectiveness of Everglades protection and restoration activities.

CONCLUSION

This report has touched on many aspects of the biogeochemical environment of the Everglades. As with any assessment of the environment at large, the long-term goal of the Everglades R-EMAP Program is to first describe, then diagnose, and finally to predict the status of the ecosystem. This report summarizes major parts of the first step for the 2005 iteration of the Program. Beyond that description, statements have been made about changes in the state of the system. The diagnosis step, initiated here, will be developed further with multivariate statistical analysis. Hopefully, models will come from these analyses to enable trend-casting and confident prediction of responses to CERP actions, and mercury and phosphorus control efforts, to a degree that will facilitate adaptive management. The next task for R-EMAP investigators will be to broaden the ecological scope of the description, while intensifying efforts to elucidate predictive relationships leading from physico-chemical drivers, through fluxes between environmental compartments, and to responses of ecological endpoints. Future publications will address topics not included here, such as studies of aquatic food webs, periphyton species composition, and landscape-scale habitat change. Program data and metadata are available to the public from USEPA [http://www.epa.gov/region4/sesd/sesdpub_completed.html.] Suggestions from the public, scientists, managers, and stakeholders in South Florida for improving the Program are welcome, and will be incorporated to the extent practicable, when the availability of funding becomes sufficiently favorable to begin planning for Phase IV.

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Appendix I. Measurements and Analytes by Medium, with abbreviations, for Everglades R-EMAP 2005.

SURFACE WATER (SW)
Depth
Temperature
Dissolved Oxygen
In-situ pH
Conductivity (COND)
Turbidity
Total Phosphorus (TP)
Soluble Reactive Phosphorus
Total Nitrogen (TN)
Total Inorganic Nitrogen (TIN)
Total Organic Nitrogen (TON)
Filtered Ammonia (FNH4)
Filtered Nitrate (FNO3)
Filtered Nitrite (FNO2)
Filtered Nitrate-Nitrite (FNN)
Dissolved Organic Carbon (DOC)
Sulfate (SO4)
Sulfide (H2S)
Alkaline Phosphatase Activity (APA)
Chlorophyll-*a* (CHLA)
Total Mercury (THg)
Methylmercury (MeHg)
MUF Phosphorus
MUF Carbon
Chloride (CL)
Bromide
Fluoride
N^{15} (in suspended particulate organic matter)
C^{13} (in suspended particulate organic matter)

SOIL (SD)
Type
Thickness
Ash-Free Dry Weight (AFDW)
Bulk Density (BD)
Mineral Content
Water Content
In-situ pH
Acid Volatile Sulfide
Methane
Carbon Dioxide
Total Carbon (TC)
Total Nitrogen (TN)
Total Phosphorus, by mass (TP…1)
Total Phosphorus, by volume (TP…2)
MUF Phosphorus
MUF Carbon
Total Mercury (THg)
Methylmercury (MeHg)

FLOC (FC)
Thickness
Ash Free Dry Weight
Bulk Density
Mineral Content
Water Content
Methane
Carbon Dioxide
Total Carbon (TC)
Total Nitrogen (TN)
Total Phosphorus (TP)
MUF Phosphorus
MUF Carbon
Total Mercury (THg)
Methylmercury (MeHg)
Chlorophyll-*a*

PERIPHYTON [PE (epiphytic), PB (benthic), PF (floating), PS (sum of all forms present)]
Bulk Density
Ash Free Dry Weight
Methylmercury (MeHg)
Total Mercury (THg)
Carbon:Nitrogen:Phosphorus Ratio

MOSQUITOFISH
Total Mercury (THgFish)
weight
length
sex

PORE WATER (PW)
Oxidation-Reduction Potential (Eh)
Soluble Reactive Phosphorus
Total Inorganic Nitrogen (TIN)
Filtered Ammonia (FNH4)
Filtered Nitrate (FNO3)
Filtered Nitrite (FNO2)
Filtered Nitrate-Nitrite (FNN)
Dissolved Organic Carbon (DOC)
Sulfate (SO4)
Sulfide (H2S)
Chloride
Bromide
Flouride

Appendix II. Median Values of Selected Parameters for the Everglades R-EMAP Program.

Analyte	Medium	Season	Phase			Units*
			1995-96	1999	2005	
Entire Study Area						
total mercury	mosquitofish	dry	185^{a}	107^{b}	52^{c}	ng/g
total phosphorus	surface water	wet	8.68^{a}	6.16^{b}	7.50^{c}	ug/l
methyl mercury	surface water	wet	0.28^{a}	0.19^{b}	0.21^{c}	ng/l
total mercury	surface water	wet		1.9^{a}	2.2^{b}	ng/l
			$1.86^{a\dagger}$			
total mercury	mosquitofish	wet	142^{a}	127^{b}	87^{c}	ng/g
methyl mercury	epiphytic periphyton	dry	2.35^{a}	1.72^{ab}	1.45^{b}	ng/g
methyl mercury	epiphytic periphyton	wet	2.13^{a}	2.31^{a}	1.70^{a}	ng/g
total phosphorus	soil	wet	343^{a}		390^{b}	mg/kg
total phosphorus	soil	wet	55.03		54.25	ug/cc
methyl mercury	floc	wet		0.83	3.00	ng/g
methyl mercury	floating periphyton	wet		1.73^{a}	1.60^{a}	ng/g
methyl mercury	benthic periphyton	wet	0.38^{a}	0.20^{ab}	0.47^{b}	ng/g
methyl mercury	soil	wet	0.43^{a}	0.39^{b}	0.49^{a}	ng/g
methyl mercury	floc	dry		0.2	3.25	ng/g
methyl mercury	floating periphyton	dry		2.19^{a}	0.85^{b}	ng/g
methyl mercury	benthic periphyton	dry	1.05^{a}	0.57^{b}	0.31^{b}	ng/g
methyl mercury	soil	dry	0.52	0.52	1.15	ug/kg
total mercury	floc	wet		158^{a}	130^{b}	ng/g
total mercury	floating periphyton	wet		38.2^{a}	15.5^{a}	ng/g
total mercury	benthic periphyton	wet	106^{a}	29.7^{b}	9.70^{b}	ng/g
total mercury	soil	wet	130	130	140	ug/kg
sulfate	surface water	wet	2.6^{a}	2.05^{a}	2.00^{b}	mg/l
total organic carbon	surface water	dry	$28.55^{a\ddagger}$		22.58^{b}	mg/l
		wet	$19.19^{a\ddagger}$		17.20^{b}	
sulfide	pore water	wet		0.11^{a}	0.12^{a}	mg/l
Core Area						
sulfate	surface water	wet	2.0	2.0	2.0	mg/l
total mercury	mosquitofish	wet	215^{a}	164^{b}	110^{c}	ng/g
conductivity	surface water	wet	383^{a}	286^{b}	407^{c}	umhos/cm
total organic carbon	surface water	wet	15.86^{a}	13.82^{b}		mg/l
sulfide	pore water	wet		0.09^{a}	0.11^{a}	mg/l
total mercury	surface water	wet	1.68^{a}	1.63^{a}	1.9^{b}	ng/l
			$1.64^{a\dagger}$			
methyl mercury	surface water	wet	0.28^{a}	0.16^{b}	0.19^{b}	ng/l
total mercury	soil	wet	140	140	140	ug/kg
methyl mercury	soil	wet	$0.47^{a b}$	0.37^{a}	0.54^{b}	ug/kg
total phosphorus	soil	wet	382^{a}		410^{a}	mg/kg
total mercury	floc	wet		145^{a}	120^{b}	ng/g
methyl mercury	floc	wet		0.83	2.90	ng/g
total mercury	epiphytic periphyton	wet	148^{a}	28.9^{b}	22.0^{b}	ng/g
methyl mercury	epiphytic periphyton	wet	2.26^{a}	2.04^{a}	1.80^{a}	ng/g
total mercury	benthic periphyton	wet	105.8^{a}	40.61^{b}	11.00^{b}	ng/g
methyl mercury	benthic periphyton	wet	0.72^{a}	0.21^{b}	$0.52^{a b}$	ng/g
total mercury	floating periphyton	wet		26.68^{a}	17.00^{a}	ng/g
methyl mercury	floating periphyton	wet		1.67^{a}	1.60^{a}	ng/g

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[a b c] Distributions with medians having different letters are different ($P \le 0.05$).

[*] Units are nanograms per gram [(ng/g) parts per billion], micrograms per liter [(ug/l) parts per billion], nanograms per liter [(ng/l) parts per trillion], milligrams per kilogram [(mg/kg) parts per million], micrograms per cubic centimeter (ug/cc), micrograms per kilogram [(ug/kg) parts per billion], milligrams per liter [(ug/l) parts per million], and micromhos per centimeter (umhos/cm).

[†] 1995 only. [‡] 1996 only.

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	THgFish	THgSW	MeHgSW	THgSD	MeHgSD	BAFTHg	BAFMeHg	THgPE	MeHgPE	THgPB	MeHgPB	THgPF	MeHgPF	THgPS	MeHgPS	THgFC	MeHgFC	TCSD	DOCPW
THgFish	1.0000																		
	N=111																		
	p= ---																		
THgSW	.0382	1.0000																	
	N=110	N=118																	
	p=.692	p= ---																	
MeHgSW	***.4702***	***.6572***	1.0000																
	N=59	*N=73*	N=118																
	p=.000	*p=.000*	p= ---																
THgSD	.2590	.2984	**.4822**	1.0000															
	N=110	N=117	N=117	N=118															
	p=.006	p=.001	p=.000	p= ---															
MeHgSD	.2926	.2747	**.3442**	**.5860**	1.0000														
	N=110	N=117	N=92	N=59	N=118														
	p=.002	p=.003	p=.001	p=.000	p= ---														
BAFTHg	**.9133**	**-.4260**	-.0120	.0682	***.4642***	1.0000													
	N=58	N=109	N=109	N=108	*N=58*	N=109													
	p=0.00	p=.000	p=.901	p=.483	*p=.000*	p= ---													
BAFMeHg	**.6477**	**-.4217**	**-.7801**	-.1966	-.0181	**.7763**	1.0000												
	N=166	N=109	N=25	N=108	N=108	N=109	N=109												
	p=0.00	p=.000	p=.000	p=.041	p=.852	p=0.00	p= ---												
THgPE	.3260	.2414	**.4511**	**.6399**	.3299	.1875	-.0572	1.0000											
	N=77	N=79	N=51	N=51	N=78	N=77	N=77	N=79											
	p=.004	p=.032	p=.001	p=.000	p=.003	p=.103	p=.621	p= ---											
MeHgPE	**.6780**	**.3860**	**.7423**	**.5890**	***.6221***	.3187	-.1482	***.5667***	1.0000										
	N=22	N=102	N=51	N=78	*N=51*	N=77	N=77	*N=51*	N=79										
	p=.001	p=.000	p=.000	p=.000	*p=.000*	p=.005	p=.198	*p=.000*	p= ---										
THgPB	.0623	.3631	.5510	.5708	.3525	-.1369	-.5142	.5623	.5552	1.0000									
	N=26	N=27	N=27	N=26	N=26	N=26	N=26	N=23	N=23	N=27									
	p=.762	p=.063	p=.003	p=.002	p=.077	p=.505	p=.007	p=.005	p=.006	p= ---									
MeHgPB	.4646	.3186	.5489	**.4818**	***.6322***	.2482	-.1399	.3925	.6274	**.6369**	1.0000								
	N=26	N=27	N=27	N=57	*N=26*	N=26	N=26	N=23	N=23	N=24	N=27								
	p=.017	p=.105	p=.003	p=.000	*p=.001*	p=.221	p=.495	p=.064	p=.001	p=.001	p= ---								
THgPF	.2452	.1910	.3166	.5832	.0723	.0840	-.1546	**.8308**	**.7920**	.6777	.7664	1.0000							
	N=18	N=20	N=20	N=20	N=20	N=18	N=18	N=13	N=14	N=4	N=4	N=20							
	p=.327	p=.420	p=.174	p=.007	p=.762	p=.740	p=.540	p=.000	p=.001	p=.322	p=.234	p= ---							
MeHgPF	.1374	.5232	***.8688***	.2814	.2129	-.2109	**-.9391**	.3065	***.8162***	.8074	.9290	.5135	1.0000						
	N=18	N=20	*N=13*	N=20	N=20	N=18	N=13	N=18	*N=14*	N=4	N=4	N=20	N=20						
	p=.587	p=.018	*p=.000*	p=.229	p=.367	p=.401	p=.000	p=.216	*p=.000*	p=.193	p=.071	p=.021	p= ---						
THgPSM	.2651	.2448	.3063	**.6339**	***-.2265***	.1290	-.0355	***.9103***	**.4417**	***.9762***	**.6315**	**.9184**	.4595	1.0000					
	N=80	N=84	N=84	N=25	*N=226*	N=80	N=80	*N=13*	N=79	*N=27*	N=24	N=13	N=20	N=84					
	p=.017	p=.025	p=.005	p=.001	*p=.001*	p=.254	p=.755	*p=.000*	p=.000	*p=.000*	p=.001	p=.000	p=.042	p= ---					
MeHgPSM	**.5830**	**.3609**	**.6921**	**.6112**	**.5432**	**.3882**	-.0320	***.4399***	***.9898***	**.6615**	***.9336***	**.6163**	***.8448***	***.6292***	1.0000				
	N=80	N=116	N=52	N=53	N=83	N=80	N=80	*N=64*	*N=13*	N=24	*N=15*	N=26	*N=17*	*N=45*	N=84				
	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.778	*p=.000*	*p=.000*	p=.000	*p=.000*	p=.001	*p=.000*	*p=.000*	p= ---				

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	THgFish	THgSW	MeHgSW	THgSD	MeHgSD	BAFTHg	BAFMeHg	THgPE	MeHgPE	THgPB	MeHgPB	THgPF	MeHgPF	THgPS	MeHgPS	THgFC	MeHgFC	TCSD	DOCPW
THgFC	-.0204	.1725	.0146	.5819	.1613	-.1099	-.0746	.6030	.2152	.4517	.2767	.6847	-.0262	.5289	.1501	1.0000			
	N=85	N=91	N=91	N=47	N=91	N=84	N=84	N=52	N=58	N=10	N=10	N=22	N=16	N=58	N=60	N=91			
	p=.853	p=.102	p=.891	p=.000	p=.127	p=.319	p=.500	p=.000	p=.105	p=.190	p=.439	p=.000	p=.923	p=.000	p=.252	p= ---			
MeHgFC	.3065	.3126	.2282	.3366	.8413	.1049	.0606	.2865	.3794	.3732	.9117	.0038	.1424	.0689	.3642	.3454	1.0000		
	N=85	N=91	N=91	N=91	N=33	N=84	N=84	N=58	N=58	N=10	N=10	N=16	N=16	N=60	N=60	N=91	N=91		
	p=.004	p=.003	p=.030	p=.001	p=.000	p=.342	p=.584	p=.029	p=.003	p=.288	p=.000	p=.989	p=.599	p=.601	p=.004	p=.001	p= ---		
TCSD	.1282	.3260	.5068	.8419	.5694	-.0653	-.3345	.5872	.6189	.8069	.6608	.4836	.1586	.4693	.6571	.6092	.3522	1.0000	
	N=110	N=117	N=117	N=59	N=59	N=108	N=108	N=51	N=51	N=26	N=26	N=20	N=20	N=53	N=53	N=33	N=80	N=118	
	p=.182	p=.000	p=.000	p=.000	p=.000	p=.502	p=.000	p=.000	p=.000	p=.000	p=.000	p=.031	p=.504	p=.000	p=.000	p=.000	p=.001	p= ---	
FDOCPW	-.0956	.5056	.5537	.4260	.6319	-.3001	-.4917	.8108	.3149	.8143	.6922	.2366	.3307	.3773	.3668	.0556	.6405	.5523	1.0000
	N=108	N=73	N=73	N=115	N=34	N=164	N=164	N=23	N=100	N=25	N=25	N=19	N=19	N=82	N=82	N=91	N=33	N=115	N=116
	p=.325	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.001	p=.000	p=.000	p=.329	p=.167	p=.000	p=.001	p=.600	p=.000	p=.000	p= ---
DOCSW	-.1090	.6480	.5953	-.5775	.2455	-.4168	-.6460	.2601	.3005	.6083	.5417	.2197	.3418	.3239	.4004	-.3567	.0267	.5324	.7755
	N=110	N=73	N=191	N=33	N=190	N=166	N=166	N=79	N=79	N=27	N=38	N=20	N=20	N=84	N=73	N=80	N=91	N=117	N=116
	p=.257	p=.000	p=0.00	p=.000	p=.001	p=.000	p=0.00	p=.021	p=.007	p=.001	p=.000	p=.352	p=.140	p=.003	p=.000	p=.001	p=.802	p=.000	p=0.00
TCFC	-.4281	.1850	-.1454	.5808	.1904	-.4475	-.2344	.6110	-.1596	.4838	.1347	.4123	-.2737	.0883	-.1241	.7849	.2332	.6390	.1903
	N=54	N=56	N=56	N=34	N=56	N=53	N=53	N=29	N=36	N=7	N=7	N=11	N=11	N=38	N=38	N=34	N=56	N=62	N=56
	p=.001	p=.172	p=.285	p=.000	p=.160	p=.001	p=.091	p=.000	p=.352	p=.271	p=.773	p=.208	p=.415	p=.598	p=.458	p=.000	p=.084	p=.000	p=.160
AFDWSD	.1329	.3365	.5381	.9044	.5730	-.0750	-.3661	.6979	.5825	.7754	.6349	.6019	.3040	.4151	.6900	.5041	.4728	.9835	.6219
	N=108	N=115	N=115	N=57	N=57	N=106	N=106	N=50	N=50	N=26	N=26	N=20	N=20	N=135	N=53	N=70	N=46	N=116	N=113
	p=.170	p=.000	p=.000	p=0.00	p=.000	p=.445	p=.000	p=.000	p=.000	p=.000	p=.000	p=.005	p=.193	p=.000	p=.000	p=.000	p=.001	p=0.00	p=.000
BDSD	-.0314	-.3752	-.5271	-.8705	.5398	.1801	.4271	-.6389	-.5987	-.7405	-.6339	-.5755	-.2831	-.4135	-.6766	-.2972	-.2053	-.9513	-.5586
	N=110	N=117	N=59	N=59	N=59	N=108	N=108	N=51	N=51	N=26	N=31	N=20	N=20	N=83	N=53	N=91	N=91	N=59	N=115
	p=.744	p=.000	p=.000	p=0.00	p=.000	p=.062	p=.000	p=.000	p=.000	p=.000	p=.000	p=.008	p=.226	p=.000	p=.000	p=.004	p=.051	p=0.00	p=.000
COND	-.0845	.0738	.4173	-.0063	-.2352	-.1038	-.2614	-.0798	.0501	.3865	.4473	-.1772	.0570	.0510	.1717	-.2116	-.2227	.0217	.3361
	N=109	N=117	N=73	N=116	N=116	N=108	N=165	N=78	N=78	N=26	N=26	N=20	N=20	N=83	N=83	N=90	N=90	N=116	N=115
	p=.383	p=.429	p=.000	p=.947	p=.011	p=.285	p=.001	p=.487	p=.663	p=.051	p=.022	p=.455	p=.811	p=.647	p=.121	p=.045	p=.035	p=.817	p=.000
CLSW	-.1748	.3718	.4673	.0699	-.0999	-.2518	-.4659	.7001	.0627	.2147	.2991	-.1793	.0268	.0229	.1358	-.1156	-.1032	.0976	.4310
	N=110	N=118	N=73	N=117	N=117	N=109	N=166	N=23	N=79	N=27	N=27	N=20	N=20	N=84	N=84	N=91	N=91	N=117	N=189
	p=.068	p=.000	p=.000	p=.454	p=.284	p=.002	p=.000	p=.000	p=.583	p=.282	p=.130	p=.449	p=.911	p=.836	p=.218	p=.275	p=.331	p=.295	p=.000
SO4SW	.0350	.4309	.6503	.1699	.0175	-.1283	-.4697	.1062	.1887	.3568	.8719	.1290	.3531	.1475	.3901	-.1845	.0167	.2679	.6056
	N=110	N=118	N=33	N=117	N=117	N=109	N=57	N=79	N=79	N=27	N=15	N=20	N=20	N=84	N=72	N=91	N=91	N=117	N=116
	p=.717	p=.000	p=.000	p=.067	p=.852	p=.184	p=.000	p=.352	p=.096	p=.068	p=.000	p=.588	p=.127	p=.180	.001	p=.080	p=.875	p=.003	p=.000
SO4PW	-.2636	.3099	.5602	-.0104	-.2313	-.3821	-.5380	-.0854	-.1993	.2900	.2561	.0298	.1701	-.0493	-.1624	-.1235	.5834	-.0011	.5968
	N=107	N=114	N=32	N=114	N=114	N=105	N=162	N=76	N=76	N=24	N=24	N=19	N=19	N=80	N=80	N=90	N=32	N=114	N=32
	p=.006	p=.001	p=.001	p=.912	p=.013	p=.000	p=.000	p=.463	p=.084	p=.169	p=.227	p=.903	p=.486	p=.664	p=.150	p=.246	p=.000	p=.991	p=.000
H2SPW	-.1381	.5060	.6080	.3328	-.0711	-.3583	-.6261	.8798	.1862	.6822	.8001	.2871	.3136	.5607	.2208	-.0443	-.0992	.4027	.7254
	N=107	N=115	N=115	N=114	N=114	N=106	N=106	N=23	N=77	N=24	N=13	N=19	N=19	N=32	N=81	N=90	N=90	N=114	N=57
	p=.156	p=.000	p=.000	p=.000	p=.452	p=.000	p=.000	p=.000	p=.105	p=.000	p=.001	p=.233	p=.191	p=.001	p=.048	p=.678	p=.352	p=.000	p=.000
PWEh	-.3111	-.1262	-.2052	.2375	.3135	-.1010	.2486	.2169	-.1830	-.8683	-.6889	.8285	.3160	-.3916	-.1505	.1852	.1332	.1321	-.1961
	N=25	N=114	N=114	N=35	N=.194	N=57	N=25	N=26	N=23	N=14	N=3	N=6	N=4	N=58	N=195	N=47	N=89	N=81	N=58
	p=.130	p=.181	p=.029	p=.170	p=.000	p=.455	p=.231	p=.060	p=.403	p=.000	p=.516	p=.042	p=.684	p=.002	p=.036	p=.213	p=.213	p=.240	p=.140
depth	.0716	-.3720	.4510	.5479	-.4431	-.0283	-.5278	.6154	.4565	.6753	.9369	.9020	.4492	.5537	.4758	-.0908	-.3174	.5999	.5307
	N=110	N=73	N=118	N=117	N=74	N=109	N=58	N=51	N=51	N=27	N=9	N=13	N=20	N=69	N=84	N=91	N=161	N=117	N=116
	p=.457	p=.001	p=.000	p=.000	p=.000	p=.770	p=.000	p=.000	p=.001	p=.000	p=.000	p=.000	p=.047	p=.000	p=.000	p=.392	p=.000	p=.000	p=.000

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	THgFish	THgSW	MeHgSW	THgSD	MeHgSD	BAFTHg	BAFMeHg	THgPE	MeHgPE	THgPB	MeHgPB	THgPF	MeHgPF	THgPS	MeHgPS	THgFC	MeHgFC	TCSD	DOCPW
APASW	**.5054**	-.2215	-.1057	-.0196	**-.4300**	**.5669**	**.5299**	-.0624	.2894	-.1337	-.2655	-.0021	-.1880	***.4411***	***.4686***	.0236	-.0504	-.1746	**-.4550**
	N=110	N=118	N=118	N=117	N=73	N=109	N=109	N=79	N=79	N=27	N=27	N=20	N=20	*N=73*	*N=73*	N=91	N=91	N=117	N=58
	p=.000	p=.016	p=.255	p=.834	p=.000	p=.000	p=.000	p=.585	p=.010	p=.506	p=.181	p=.993	p=.427	*p=.000*	*p=.000*	p=.824	p=.635	p=.060	p=.000
CHLASW	-.1240	.1970	.0405	.0453	.2532	**-.2800**	**-.2581**	.0623	.0569	.0546	-.2421	.0072	.1613	.1377	.0703	.1888	.2354	.0333	.1164
	N=110	N=118	N=118	N=117	N=117	N=165	N=165	N=79	N=79	N=27	N=27	N=20	N=20	N=84	N=84	N=91	N=91	N=117	N=116
	p=.197	p=.033	p=.664	p=.628	p=.006	p=.000	p=.001	p=.585	p=.619	p=.787	p=.224	p=.976	p=.497	p=.212	p=.525	p=.073	p=.025	p=.721	p=.213
TPSW	**-.3804**	***.8789***	***.6794***	.1350	.1429	**-.4360**	**-.4656**	.1819	.0885	.0174	.2126	.1541	.2778	.1126	.0642	.0141	.1134	.1460	.1837
	N=109	*N=33*	*N=33*	N=116	N=116	N=108	N=108	N=78	N=78	N=27	N=27	N=20	N=20	N=83	N=83	N=90	N=90	N=116	N=115
	p=.000	*p=.000*	*p=.000*	p=.149	p=.126	p=.000	p=.000	p=.111	p=.441	p=.931	p=.287	p=.517	p=.236	p=.311	p=.564	p=.895	p=.287	p=.118	p=.049
TPFC	**-.5834**	.0293	-.2992	.0950	.0832	**-.5610**	-.3752	.3529	-.3196	.0441	.6016	-.1188	-.1089	.0181	-.2629	**.6254**	**.7130**	.1403	.2943
	N=54	N=56	N=56	N=56	N=56	N=53	N=53	N=36	N=36	N=7	N=7	N=11	N=11	N=38	N=38	N=34	N=31	N=56	N=56
	p=.000	p=.830	p=.025	p=.486	p=.542	p=.000	p=.006	p=.035	p=.057	p=.925	p=.153	p=.728	p=.750	p=.914	p=.111	p=.000	p=.000	p=.303	p=.028
TPSD1	-.0783	*.5420*	***.6254***	**.6015**	**.6454**	-.1909	**-.3185**	**.3259**	.3556	.4426	**.5736**	.0689	.0942	**.3047**	**.5646**	.0658	**.6174**	**.6343**	**.5034**
	N=110	*N=33*	*N=33*	N=59	N=45	N=108	N=108	N=102	N=78	N=26	N=31	N=20	N=20	N=136	N=53	N=91	N=47	N=108	N=115
	p=.416	*p=.001*	*p=.000*	p=.000	p=.000	p=.048	p=.001	p=.001	p=.001	p=.024	p=.001	p=.773	p=.693	p=.000	p=.000	p=.536	p=.000	p=.000	p=.000
TPSD2	-.0966	***.5499***	***.6196***	**-.6341**	-.1856	.0616	.2468	**-.5065**	**-.5335**	-.4692	-.0413	**-.9189**	-.3337	**-.4862**	**-.4579**	-.2358	**.4662**	**-.7816**	**.5511**
	N=110	*N=33*	*N=33*	N=59	N=118	N=108	N=108	N=51	N=51	N=26	N=26	N=13	N=20	N=52	N=52	N=91	N=70	N=59	N=34
	p=.315	*p=.001*	*p=.000*	p=.000	p=.044	p=.526	p=.010	p=.000	p=.000	p=.016	p=.841	p=.000	p=.151	p=.000	p=.001	p=.024	p=.000	p=.000	p=.001
TNSW	**.4663**	**.4471**	**.3055**	.2042	.1197	-.2211	-.2886	.0342	-.0181	.2027	.1081	-.0103	.0845	.1340	.1323	.0788	.0702	.2696	**.4108**
	N=56	N=118	N=118	N=117	N=117	N=109	N=109	N=79	N=79	N=27	N=27	N=20	N=20	N=84	N=84	N=91	N=91	N=117	N=116
	p=.000	p=.000	p=.001	p=.027	p=.199	p=.021	p=.002	p=.765	p=.875	p=.310	p=.592	p=.966	p=.723	p=.224	p=.230	p=.458	p=.508	p=.003	p=.000
TONSW	.0089	**.4437**	.2734	.1510	.0827	-.2058	-.2489	.0721	-.0672	.1537	.0698	-.0512	.0360	.1916	.0766	.0602	.0564	.2486	**.4081**
	N=110	N=118	N=118	N=117	N=117	N=109	N=109	N=79	N=79	N=27	N=27	N=20	N=20	N=84	N=84	N=91	N=91	N=117	N=116
	p=.927	p=.000	p=.003	p=.104	p=.375	p=.032	p=.009	p=.528	p=.556	p=.444	p=.730	p=.830	p=.880	p=.081	p=.489	p=.571	p=.596	p=.007	p=.000
TNFC	-.3047	.1064	*-.4077*	**.4141**	.1786	-.3276	-.1761	**.6663**	-.0590	.6006	.0203	.5114	-.1551	.1199	-.0617	**.7966**	.2095	**.5429**	.1191
	N=54	N=56	*N=62*	N=65	N=56	N=53	N=53	N=29	N=36	N=7	N=7	N=11	N=11	N=38	N=38	N=34	N=56	N=62	N=56
	p=.025	p=.435	*p=.001*	p=.001	p=.188	p=.017	p=.207	p=.000	p=.732	p=.154	p=.966	p=.108	p=.649	p=.473	p=.713	p=.000	p=.121	p=.000	p=.382
TNSD	.1317	**.3024**	**.5183**	**.8987**	**.5696**	-.0604	***-.3383***	**.6543**	**.6083**	***.8062***	**.6452**	.5264	.2478	**.4191**	**.6497**	**.4301**	.1829	***.9624***	**.5842**
	N=110	N=117	N=59	N=59	N=59	N=108	*N=108*	N=51	N=51	*N=26*	N=26	N=20	N=20	N=136	N=53	N=70	N=91	*N=59*	N=115
	p=.170	p=.001	p=.000	p=0.00	p=.000	p=.534	*p=.000*	p=.000	p=.000	*p=.000*	p=.000	p=.017	p=.292	p=.000	p=.000	p=.000	p=.083	*p=0.00*	p=.000
FNH4PW	**.2912**	***.3888***	.1349	.0859	**-.2930**	.2381	.0683	.2020	**.4067**	***.7342***	.5359	***.8924***	.2148	***.5948***	**.4692**	-.0004	-.1403	.0138	-.0506
	N=167	*N=73*	N=116	N=115	N=195	N=107	N=107	N=77	N=77	*N=25*	N=25	*N=12*	N=19	*N=92*	N=68	N=91	N=91	N=115	N=116
	p=.000	*p=.001*	p=.149	p=.361	p=.000	p=.014	p=.485	p=.078	p=.000	*p=.000*	p=.006	*p=.000*	p=.377	*p=.000*	p=.000	p=.997	p=.185	p=.884	p=.589
FNNPW	-.0486	-.0663	-.0794	.0391	**-.4018**	.0026	.0474	***.8024***	-.0052	.2889	.1317	.2252	.0133	**.5391**	.0521	**.3388**	.1119	.0338	.1701
	N=108	N=116	N=116	N=115	N=92	N=107	N=107	*N=23*	N=77	N=25	N=25	N=19	N=19	N=68	N=82	N=161	N=91	N=115	N=116
	p=.617	p=.479	p=.397	p=.678	p=.000	p=.978	p=.628	*p=.000*	p=.964	p=.161	p=.530	p=.354	p=.957	p=.000	p=.642	p=.000	p=.291	p=.720	p=.068
FNO3PW	-.0211	-.0563	-.1314	-.0231	**-.3707**	.0233	**.3816**	**.4381**	-.1646	.2091	.0818	.2375	.0208	**.5307**	-.0927	**.3574**	.0524	-.0564	-.0160
	N=108	N=116	N=116	N=115	N=92	N=107	N=82	N=62	N=77	N=25	N=25	N=19	N=19	N=68	N=82	N=161	N=91	N=115	N=116
	p=.828	p=.549	p=.160	p=.806	p=.000	p=.811	p=.000	p=.000	p=.153	p=.316	p=.697	p=.328	p=.933	p=.000	p=.408	p=.000	p=.622	p=.549	p=.865
FNO2SW	-.0643	**.3483**	**.3533**	.1495	.1075	-.2059	**-.3672**	.0534	.1301	.4650	.1809	.2184	.2661	.1716	.1969	.0264	.0459	.1231	.2490
	N=110	N=118	N=191	N=117	N=117	N=109	N=166	N=79	N=79	N=27	N=27	N=20	N=20	N=84	N=84	N=91	N=91	N=117	N=116
	p=.504	p=.000	p=.000	p=.108	p=.249	p=.032	p=.000	p=.640	p=.253	p=.015	p=.367	p=.355	p=.257	p=.119	p=.073	p=.803	p=.666	p=.186	p=.007
TINPW	**.2889**	***.3933***	.1409	.0871	**-.3128**	.2098	.0502	.2434	**.3776**	***.7359***	.5316	***.8880***	.2196	***.6035***	**.4221**	-.0099	-.1511	.0187	.0154
	N=167	*N=73*	N=116	N=115	N=195	N=107	N=107	N=77	N=77	*N=25*	N=25	*N=12*	N=19	*N=92*	N=68	N=91	N=91	N=115	N=116
	p=.000	*p=.001*	p=.131	p=.355	p=.000	p=.030	p=.608	p=.033	p=.001	*p=.000*	p=.006	*p=.000*	p=.366	*p=.000*	p=.000	p=.926	p=.153	p=.843	p=.870

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	DOCSW	**TCFC**	**AFDWSD**	**BDSD**	**COND**	**CLSW**	**SO4SW**	**SO4PW**	**H2SPW**	**PWEh**	**depth**	**APASW**	**CHLASW**	**TPSW**	**TPFC**	**TPSD1**	**TPSD2**
THgFC																	
MeHgFC																	
TCSD																	
FDOCPW																	
DOCSW	1.0000																
	N=118																
	p= ---																
TCFC	.0260	1.0000															
	N=56	N=56															
	p=.849	p= ---															
AFDWSD	**.6003**	***.7257***	1.0000														
	N=115	*N=62*	N=116														
	p=.000	*p=.000*	p= ---														
BDSD	**-.5614**	***-.5708***	**-.9493**	1.0000													
	N=117	*N=62*	N=57	N=118													
	p=.000	*p=.000*	p=0.00	p= ---													
COND	***.8550***	-.2681	.0364	.0603	1.0000												
	N=58	N=55	N=114	N=116	N=117												
	p=.000	p=.048	p=.701	p=.520	p= ---												
CLSW	***.8542***	-.1340	.1049	-.0874	***.9829***	1.0000											
	N=118	N=56	N=115	N=117	*N=33*	N=118											
	p=0.00	p=.325	p=.265	p=.349	*p=0.00*	p= ---											
SO4SW	***.8438***	-.2158	**.3079**	-.2253	***.8373***	**.7917**	1.0000										
	N=118	N=56	N=115	N=117	*N=117*	N=118	N=118										
	p=0.00	p=.110	p=.001	p=.015	*p=0.00*	p=0.00	p= ---										
SO4PW	***.6201***	-.0211	.0672	-.0671	***.6292***	**.7439**	**.7914**	1.0000									
	N=114	N=56	N=112	N=114	*N=113*	N=32	N=72	N=115									
	p=.000	p=.877	p=.481	p=.478	*p=.000*	p=.000	p=.000	p= ---									
H2SPW	**.7943**	.0413	**.4803**	**-.4359**	**.6701**	**.7887**	***.7697***	**.8057**	1.0000								
	N=115	N=55	N=55	N=114	N=33	N=33	*N=115*	N=33	N=115								
	p=0.00	p=.765	p=.000	p=.000	p=.000	p=.000	*p=.000*	p=.000	p= ---								
PWEh	***-.3335***	*.3309*	*.2099*	*-.1310*	***-.8057***	***-.8163***	***-.3700***	*-.2933*	***-.3863***	*1.0000*							
	N=114	*N=65*	*N=81*	*N=81*	*N=33*	*N=33*	*N=114*	*N=112*	*N=113*	*N=114*							
	p=.000	*p=.007*	*p=.060*	*p=.244*	*p=.000*	*p=.000*	*p=.000*	*p=.002*	*p=.000*	*p=---*							
depth	**.6004**	.1688	**.6901**	**-.6385**	.2159	**-.3745**	**.4204**	.2435	**.6664**	***-.3406***	1.0000						
	N=118	N=56	N=57	N=59	N=117	N=92	N=118	N=114	N=57	*N=195*	N=118						
	p=.000	p=.214	p=.000	p=.000	p=.019	p=.000	p=.000	p=.009	p=.000	*p=.000*	p= ---						

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	DOCSW	TCFC	AFDWSD	BDSD	COND	CLSW	SO4SW	SO4PW	H2SPW	PWEh	depth	APASW	CHLASW	TPSW	TPFC	TPSD1	TPSD2
APASW	-.3749	-.3199	-.1883	.2020	-.2675	-.3400	-.2821	-.4751	-.3814	.1478	-.1021	1.0000					
	N=118	N=118	N=115	N=117	N=117	N=118	N=191	N=114	N=115	N=114	N=118	N=118					
	p=.000	p=.000	p=.044	p=.029	p=.004	p=.000	p=.000	p=.000	p=.000	p=.117	p=.271	p= ---					
CHLASW	.0736	.2960	.0551	-.0531	.4237	.0273	-.3814	-.3832	-.0404	.2389	-.1798	.6531	1.0000				
	N=118	N=56	N=115	N=117	N=58	N=118	N=72	N=71	N=115	N=186	N=118	N=32	N=118				
	p=.429	p=.027	p=.559	p=.570	p=.001	p=.769	p=.001	p=.001	p=.668	p=.001	p=.051	p=.000	p= ---				
TPSW	.5551	.1813	.1824	-.2084	.1841	.3274	.2076	.2512	.2212	-.1460	.0869	-.5349	.3359	1.0000			
	N=33	N=56	N=114	N=116	N=116	N=117	N=117	N=114	N=114	N=33	N=117	N=117	N=117	N=117			
	p=.001	p=.181	p=.052	p=.025	p=.048	p=.000	p=.025	p=.007	p=.018	p=.418	p=.351	p=.000	p=.000	p= ---			
TPFC	.2100	.7855	.4594	-.4249	.0809	.1730	.0668	.5372	.1875	.1799	-.0442	-.6617	.2903	.4588	1.0000		
	N=56	N=34	N=62	N=62	N=55	N=56	N=56	N=34	N=55	N=34	N=56	N=56	N=56	N=56	N=56		
	p=.120	p=.000	p=.000	p=.001	p=.557	p=.202	p=.625	p=.001	p=.170	p=.309	p=.747	p=.000	p=.030	p=.000	p= ---		
TPSD1	.4744	.4811	.7599	-.6795	.3217	.3512	.2611	.2592	.2598	.2547	.3047	-.6426	.1110	.6470	.7649	1.0000	
	N=117	N=62	N=108	N=108	N=116	N=117	N=190	N=193	N=192	N=58	N=117	N=33	N=117	N=33	N=62	N=118	
	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.054	p=.001	p=.000	p=.233	p=.000	p=.000	p= ---	
TPSD2	-.2865	-.2393	-.7583	.8304	.2329	.0829	.5871	.4071	-.2823	.1476	-.6486	-.4657	-.4601	.5696	.2535	.2577	1.0000
	N=190	N=56	N=57	N=59	N=116	N=117	N=33	N=79	N=114	N=58	N=59	N=73	N=72	N=33	N=56	N=226	N=118
	p=.000	p=.076	p=.000	p=.000	p=.012	p=.374	p=.000	p=.000	p=.002	p=.272	p=.000	p=.000	p=.000	p=.001	p=.059	p=.000	p= ---
TNSW	.6602	.1597	.2764	-.2526	.5015	.5506	.5783	.4294	.5251	-.2638	.1913	.3867	.1601	-.0347	.1725	.1244	-.1953
	N=118	N=56	N=115	N=117	N=117	N=118	N=118	N=114	N=115	N=58	N=118	N=72	N=118	N=117	N=56	N=117	N=117
	p=.000	p=.240	p=.003	p=.006	p=.000	p=.000	p=.000	p=.000	p=.000	p=.045	p=.038	p=.001	p=.083	p=.710	p=.204	p=.181	p=.035
TONSW	.6604	.1524	.2337	-.2283	.5067	.5608	.5726	.4169	.5022	-.2610	.1406	-.1596	.1930	-.0511	.1402	.0731	-.2073
	N=118	N=56	N=115	N=117	N=117	N=118	N=118	N=114	N=115	N=185	N=118	N=118	N=118	N=117	N=56	N=117	N=117
	p=.000	p=.262	p=.012	p=.013	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000	p=.129	p=.084	p=.036	p=.584	p=.303	p=.434	p=.025
TNFC	-.0808	.9490	.6260	-.5680	-.3346	-.2625	-.3174	-.1505	-.0816	.3625	.1540	-.1495	.2538	.0962	.7149	.1832	-.2893
	N=56	N=34	N=62	N=62	N=117	N=56	N=118	N=56	N=55	N=56	N=56	N=56	N=56	N=56	N=34	N=56	N=118
	p=.554	p=.000	p=.000	p=.000	p=.000	p=.051	p=.000	p=.268	p=.554	p=.006	p=.257	p=.271	p=.059	p=.480	p=.000	p=.177	p=.001
TNSD	.5514	.6225	.9827	-.9396	.0341	.0785	.2724	.0121	.4032	.1082	.6963	-.1413	.0263	.1734	.0967	.7157	-.7544
	N=117	N=62	N=57	N=59	N=116	N=117	N=117	N=114	N=114	N=81	N=59	N=117	N=117	N=116	N=56	N=108	N=59
	p=.000	p=.000	p=0.00	p=0.00	p=.716	p=.400	p=.003	p=.899	p=.000	p=.336	p=.000	p=.129	p=.778	p=.063	p=.478	p=.000	p=.000
FNH4PW	.3891	-.2577	.0258	.0177	.0759	-.0226	.0439	-.0822	.0459	-.2479	.4766	.4669	-.0822	-.0916	-.4874	-.2995	-.1882
	N=73	N=56	N=113	N=115	N=115	N=116	N=116	N=114	N=115	N=93	N=92	N=58	N=116	N=115	N=56	N=195	N=115
	p=.001	p=.055	p=.786	p=.851	p=.420	p=.809	p=.640	p=.385	p=.626	p=.017	p=.000	p=.000	p=.381	p=.330	p=.000	p=.000	p=.044
FNNPW	.4528	.0176	.0669	-.0336	.0336	.0205	.0137	-.0088	.5001	-.1545	.5112	-.0516	.0728	-.0209	.1414	.0461	-.0020
	N=73	N=56	N=113	N=115	N=115	N=116	N=116	N=114	N=57	N=93	N=91	N=116	N=116	N=115	N=56	N=115	N=115
	p=.000	p=.898	p=.482	p=.722	p=.722	p=.827	p=.884	p=.926	p=.000	p=.139	p=.000	p=.582	p=.437	p=.824	p=.299	p=.625	p=.983
FNO3PW	-.3713	.0173	-.0229	-.3694	.0773	.0608	.5538	.5005	.7667	-.1529	.4361	-.0617	.0837	-.0168	.1840	-.0123	.0331
	N=91	N=56	N=113	N=80	N=115	N=116	N=58	N=58	N=57	N=35	N=91	N=116	N=116	N=115	N=56	N=115	N=115
	p=.000	p=.899	p=.810	p=.001	p=.412	p=.517	p=.000	p=.000	p=.000	p=.381	p=.000	p=.511	p=.372	p=.859	p=.175	p=.896	p=.726
FNO2SW	.5277	.0028	.1716	-.1474	.4079	.4727	.4876	.3574	.3948	-.0928	.1390	-.2256	.1552	.4158	.1021	.3982	-.0019
	N=118	N=56	N=115	N=117	N=117	N=118	N=118	N=114	N=115	N=80	N=118	N=118	N=118	N=117	N=56	N=117	N=117
	p=.000	p=.984	p=.067	p=.113	p=.000	p=.000	p=.000	p=.000	p=.000	p=.413	p=.133	p=.014	p=.093	p=.000	p=.454	p=.000	p=.984
TINPW	.4040	-.2451	.0408	.0143	.0879	-.0053	.0677	-.0573	.0775	-.2519	.4910	.3740	-.0830	-.1013	-.4901	-.2911	-.1895
	N=73	N=56	N=113	N=115	N=115	N=116	N=116	N=114	N=115	N=93	N=92	N=116	N=116	N=115	N=56	N=195	N=115
	p=.000	p=.069	p=.668	p=.880	p=.350	p=.955	p=.470	p=.545	p=.410	p=.015	p=.000	p=.000	p=.376	p=.281	p=.000	p=.000	p=.043

Appendix III. Pearson correlation coefficients for 2005 Program data. See last page for key.

	TNSW	**TONSW**	**TNFC**	**TNSD**	**FNH4PW**	**FNNPW**	**FNO3PW**	**FNO2SW**	**TINPW**
APASW									
CHLASW									
TPSW									
TPFC									
TPSD1									
TPSD2									
TNSW	1.0000								
	N=118								
	p= ---								
TONSW	***.9630***	1.0000							
	N=118	N=118							
	p=0.00	p= ---							
TNFC	.1169	.1017	1.0000						
	N=56	N=56	N=56						
	p=.391	p=.456	p= ---						
TNSD	.2389	.2000	***.6538***	1.0000					
	N=117	N=117	*N=62*	N=118					
	p=.009	p=.031	*p=.000*	p= ---					
FNH4PW	.0538	.0255	-.1361	.0608	1.0000				
	N=116	N=116	N=56	N=115	N=116				
	p=.566	p=.786	p=.317	p=.519	p= ---				
FNNPW	.1776	.2015	.0583	.0755	**.5161**	1.0000			
	N=116	N=116	N=56	N=115	N=92	N=116			
	p=.057	p=.030	p=.670	p=.423	p=.000	p= ---			
FNO3PW	.1611	.2243	.0240	-.0166	**.4976**	**.9319**	1.0000		
	N=116	N=116	N=56	N=115	N=92	N=196	N=116		
	p=.084	p=.015	p=.861	p=.860	p=.000	p=0.00	p= ---		
FNO2SW	**.5642**	***.4091***	.0401	.1247	**.4064**	.2430	.2004	1.0000	
	N=118	*N=118*	N=56	N=117	N=73	N=116	N=116	N=118	
	p=.000	*p=.000*	p=.769	p=.181	p=.000	p=.009	p=.031	p= ---	
TINPW	.0927	.0664	-.1121	.0792	***.9996***	**.5832**	**.5628**	**.3960**	1.0000
	N=116	N=116	N=56	N=115	*N=34*	N=92	N=92	N=73	N=116
	p=.322	p=.479	p=.411	p=.400	*p=0.00*	p=.000	p=.000	p=.001	p= ---

Notes for correlation matrix:

Top number is Pearson r; N = sample size, and p = probability.

See Appendix I for codes to analytes and media, e.g., THgFish = total mercury (THg) in mosquitofish (Fish).

Non-significant, trivial, weak, spurious, and auto-correlations are not excluded.

Color code: black = entire study area, wet season only; red = core area only (see page 80), wet season; blue = core area, wet and dry seasons combined; green = core area, dry season; brown = entire area, wet and dry seasons combined; violet = entire area, dry season.

Coefficients in **bold font** are considered statistically significant. The 0.001 level was selected for this matrix. Some p-values of bolded coefficients are shown as equaling 0.001 (instead of being less than 0.001) due to rounding. P-values less than 0.0006 are reported as 0.000.

Numbers in *italics* are from un-transformed data. All others are from natural log-transformed datasets.

The largest significant coefficient available (see color code above) is displayed in each cell.

About the authors

Peter Kalla is a senior scientist in the Ecology Branch at the USEPA Region 4 Laboratory. He has 23 years of professional experience in wetland, watershed, and wildlife research and management, including 19 years spent in the study of sub-tropical ecosystems in Florida. He has led $4.7 million worth of work in wetland and watershed assessment and planning, mostly within the R-EMAP and EMAP programs. He has also conducted research on the use of remote sensing in demarcation and assessment of Coastal Plain wetlands. He is an author on about 70 technical publications. Dr. Kalla has served as a natural resources policy advisor to numerous local, state, regional, and national government agencies. He received his B.S. in Zoology from Auburn University in 1975, his M.S. in Biology from East Tennessee State University in 1979, and his Ph.D. in Ecology from the University of Tennessee, Knoxville in 1991.

Daniel Scheidt serves as USEPA's Senior Scientist on South Florida and Everglades water quality issues, advising senior managers regarding various scientific, policy, and regulatory matters. He was employed at the South Florida Research Center at Everglades National Park from 1982-1991 as a hydrologist where he directed hydrological monitoring and water quality monitoring and research. He has 25 years of professional experience regarding Everglades science. He is an author on about 50 technical reports or scientific publications concerning water quality, mercury contamination, nutrient enrichment, environmental assessment, or ecological risk assessment. He completed a M. S. in Environmental Science with a concentration in Water Resources at the Indiana University School of Public and Environmental Affairs in Bloomington.

Photographic Acknowledgements
Table of Contents: person in cattail, Phyllis Meyer; Figure 3: Everglades National Park; Figures 8, 14, 27, 29, 47, 53 and 62: satellite base map, South Florida Water Management District; Figure 15: lower right, Mel Parsons; Figure 36: Danny Adams; Inside back cover: Peter Kalla; All other photos: Daniel Scheidt.

The R-EMAP flight line at FIU on a morning in November of 2005.