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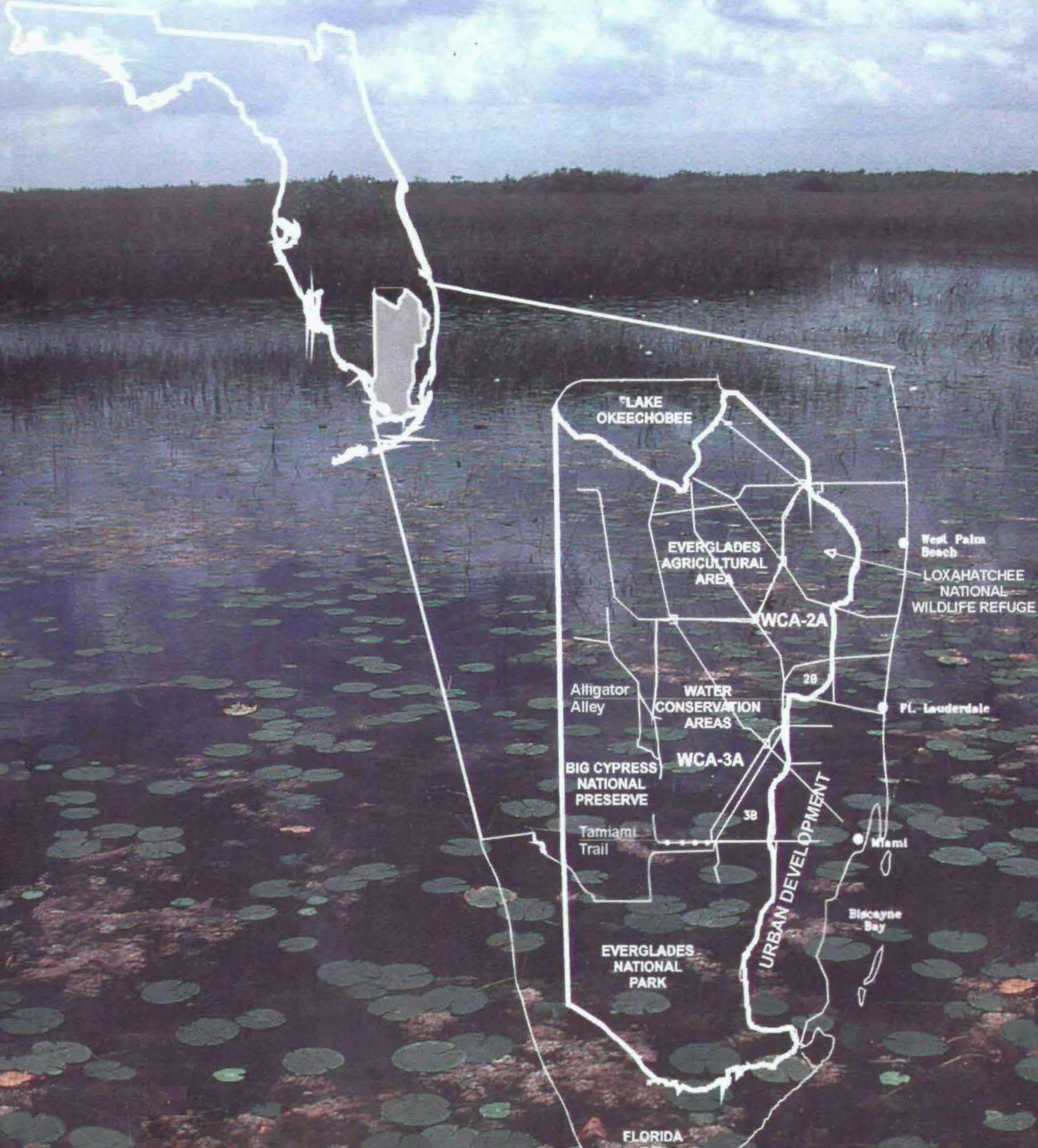
South Florida Ecosystem Assessment Interim Report



Monitoring for Adaptive Management: Implications for Ecosystem Restoration

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SOUTH FLORIDA ECOSYSTEM ASSESSMENT

MONITORING FOR ADAPTIVE MANAGEMENT: IMPLICATIONS FOR ECOSYSTEM RESTORATION
(Interim Report)

by

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The South Florida Ecosystem Assessment is being accomplished through the cooperation of federal and state natural resource agency specialists. The agencies include the US Environmental Protection Agency, the US Fish and Wildlife Service, the US Geological Survey, the US National Park Service, the Florida Department of Environmental Protection, the South Florida Water Management District, and the Florida Game and Freshwater Fish Commission. Florida International University Southeast Environmental Research Program is also a partner in this effort.

LIST OF ABBREVIATIONS

% OM = percent organic matter
CM = centimeter
FT = foot
KM = kilometer
kg/yr = kilogram per year
ppb = parts per billion (ug/L)
ppt = parts per trillion (ng/L)
ng/L = nanogram per liter (ppt)
mg/L = milligram per liter (ppm)
ug/kg = parts per billion (ppb)
uMol/hr = micromoles per hour

Hg = mercury
Hg° = elemental mercury
HgII = inorganic mercury
MeHg = methylmercury

APTMD = Air, Pesticides, and Toxics Management Division
EAA = Everglades Agricultural Area
EMAP = Environmental Monitoring and Assessment Program
FIU SERP = Florida International University Southeastern Environmental Research Program
NHEERL - ATHENS = National Health and Environmental Exposure Research Laboratory - Athens, GA
NHEERL - RTP = National Health and Environmental Exposure Research Laboratory - Research Triangle Park, NC
NPS = National Park Service
ORC = Office of Regional Counsel
REMAP = Regional Environmental Monitoring and Assessment Program
SESD = Science and Ecosystem Support Division
SFWMD = South Florida Water Management District
US EPA = United States Environmental Protection Agency
USGS = United States Geological Survey
WCA = Water Conservation Area

BASS = Bioaccumulation and Aquatic System Simulator Model
MERC5 = Mercury Cycling Model, Version 5

EXECUTIVE SUMMARY

The purpose of this interim report is to introduce the systemwide (4000-square-mile) scope of the monitoring project in the Everglades ecosystem and to present preliminary findings on the mercury contamination, eutrophication, habitat alteration, and hydropattern modification issues. The greatest threat to the Everglades ecosystem is to assume these issues are independent. The monitoring in this project strongly supports the federal and state Everglades restoration efforts and will provide a means to evaluate present and future management actions. This project is focused on the ecological risk assessment process and guided by a set of policy relevant questions. A statistical survey design was used to select 200 canal and 500 marsh sampling stations, a quarter of which were sampled during successive wet and dry seasons over two years. These data allow quantitative estimation of the relative risk to the ecological resources from multiple environmental threats. Marsh monitoring has been conducted during two years, one of which was the wettest year on record. To determine the range of natural variance to support and validate mercury modeling, process studies, and future assessments, this monitoring should continue.

The highest mercury concentrations in algae, fish, and great egrets have been found to occur in Water Conservation Area 3 between Alligator Alley and Tamiami Trail. No single point source has been identified that contributes directly to these high mercury levels. Atmospheric mercury loading from precipitation is from 35 to 70 times greater in the publicly owned Everglades than mercury loading in canal water coming from the Everglades Agricultural Area. Incineration in the urban areas is likely the primary source of atmospheric mercury.

Several policy and management implications arose from these preliminary results including: (1) the current chronic mercury aquatic life criterion is underprotective and needs to be revised; (2) discharging phosphorus at the current initial control target of 50 ppb will continue to allow eutrophication of over 95% of the Everglades marshes; and (3) ecological restoration must consider hydropattern modification, nutrient loading, mercury cycling, and habitat alteration simultaneously, not independently.

Comparative ecological risk assessment is a critical element in adaptive management for ecosystem restoration. This ecosystem assessment project provides a critical framework and foundation for assessing the effectiveness of Everglades ecosystem restoration activities into the 21st century.

Contents

US EPA REGION 4

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PHOTO CREDITS

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INTRODUCTION

SOUTH FLORIDA EVERGLADES

"There are no other Everglades in the world. They have always been one of the unique regions of the earth. Nothing anywhere else is like them: Their vast glittering openness, wider than the enormous visible round of the horizon, the racing free saltiness and sweetness of their massive winds, under the dazzling blue heights of space[1]."

Figure 1. USGS satellite image of South Florida: light areas on the east indicate urban areas; dark areas in the center are the remnant Everglades; and the red area at the top is the EAA.

The Florida Everglades is one of the largest freshwater marshes in the world. Just one hundred years ago this vast wilderness encompassed over 4000 square miles, extending 100 miles from the shores of Lake Okeechobee south to the coast. Subtle irregularities in ground elevation resulted in a mosaic of sawgrass marsh, wet prairies, sloughs, and tree islands. The intermingling of temperate and Caribbean flora created habitat for a variety of fauna, including the Florida panther, the alligator, and the hundreds of thousands of wading birds with which the Everglades were synonymous. The unique and timeless characteristics of the Everglades were described by Marjory Stoneman Douglas in her classic work, The Everglades: River of Grass. This work brought the Everglades to national and international attention as a natural resource worthy of preservation.

"They were changeless. They were changed[1]."

During the last century, the Everglades ecosystem has been altered to provide for extensive agricultural and urban development (Figure 1). Today, 50% of the historic Everglades wetlands have been drained, and an

[1]Marjory Stoneman Douglas. 1947. **The Everglades: River of Grass**. Banyan Books. Sarasota, FL.

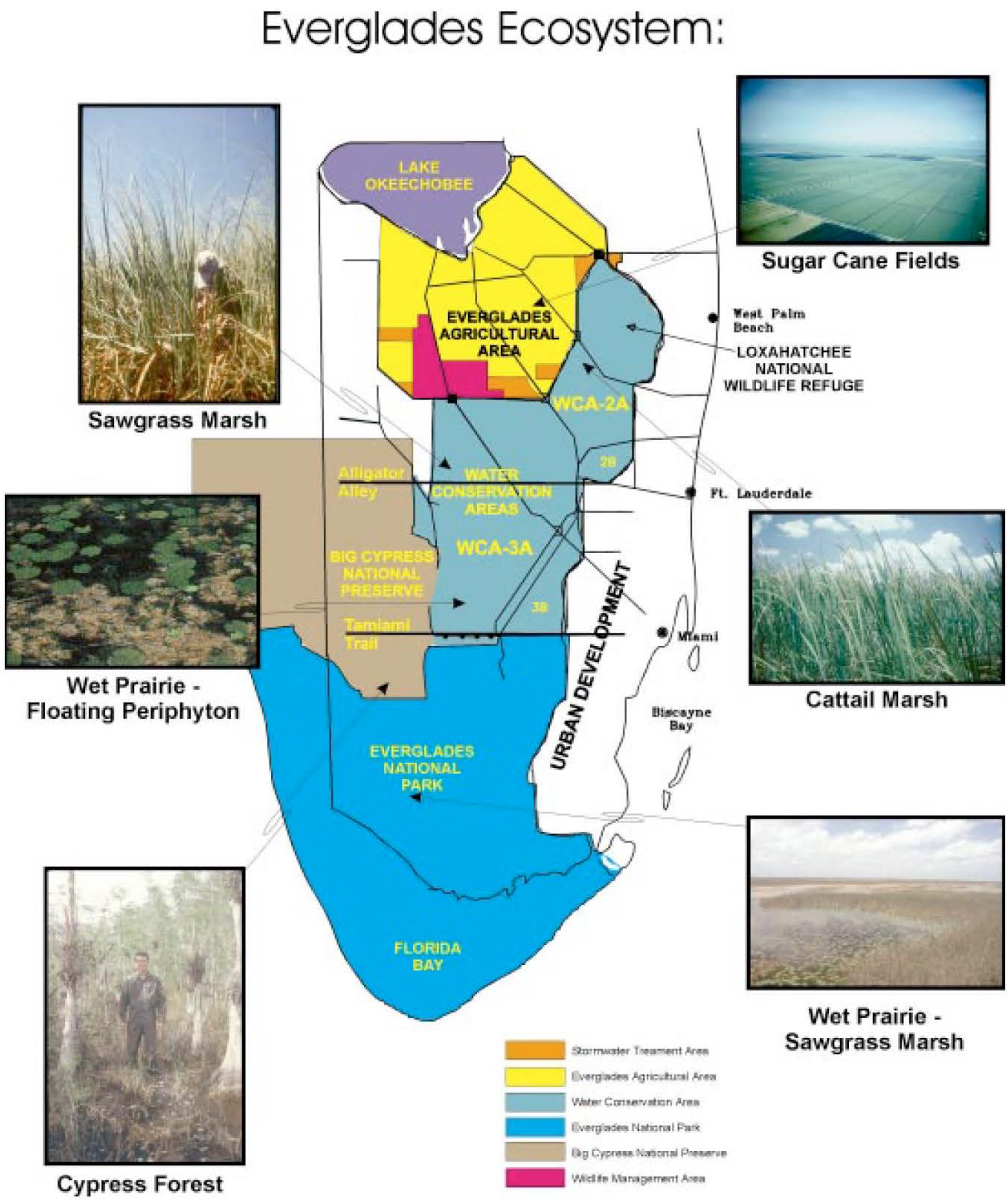


Figure 2. Everglades ecosystem communities.

expanding South Florida human population of nearly 6 million competes for this ecosystem's water and land.

The Everglades changed dramatically as drainage canals were dug and agricultural and urban development increased in the 20th century. Most of the remaining Everglades are in Loxahatchee National Wildlife Refuge, Everglades National Park, or the Water Conservation Areas (WCAs) (Figure 2). Today, Everglades National Park includes only one-fifth of the original river of grass that once spread over more than 2 million acres. One-fourth of the historic Everglades is now in extensive agricultural production within the 1000-square-mile Everglades Agricultural Area (EAA), where sugar cane and vegetables are grown on fertile peat soils. Big Cypress National Preserve protects forested swamp resources within the Everglades watershed. Although half of the 16,000-square-mile Everglades watershed is in public ownership, there are a number of environmental issues that must be resolved to restore and protect the Everglades ecosystem, including eutrophication; mercury contamination of gamefish, wading birds, and other top predators; habitat alteration and loss; hydropattern modification; water supply conflicts; endangered species; and nuisance exotic species introductions.

ISSUES

Eutrophication

Nutrient loading from the Everglades Agricultural Area and urban areas has significantly increased nutrient concentrations, particularly phosphorus, in the downstream Water Conservation Areas and the Park, resulting in major eutrophic impacts to these wetland systems (Figure 3). Among the progressive Everglades eutrophic impacts are increased soil phosphorus content, changed natural periphyton communities, increased oxygen-demanding organic matter, loss of water dissolved oxygen, loss of native sawgrass plant communities, loss of important wading bird foraging habitat, and conversion of wet prairie plant communities to cattails. These collective changes are systemic and impact the structure and function of the aquatic

Figure 3. Eutrophication promotes cattail expansion.

Figure 4. Florida panther, an endangered species, died from mercury toxicity.

system. The Florida Department of Environmental Protection (FDEP) has concluded that eutrophication of the Everglades results in the violation of four Florida water quality standards to protect fish and wildlife and creates an imbalance in natural populations of aquatic flora and fauna, with a resulting loss in biological integrity. Some eutrophic impacts, such as periphyton community changes, are thought to be short-term and reversible if nutrient additions can be significantly decreased. Other impacts are considered long-term (decades), such as loading peat soil with excess phosphorus that triggers the loss of native plant communities and foraging habitat. The nutrient levels required to sustain the natural balance of oligotrophic plants and animals into future decades and centuries are currently under debate. There are still many marsh areas where natural water phosphorus concentrations are less than 10 ppb. A combination of agricultural best management practices and construction of over 40,000 acres of wetlands (Stormwater Treatment Areas) are being implemented in an attempt to control phosphorus loadings. The effectiveness of these controls in reducing nutrient concentrations to near historic levels, however, is not yet known.

Figure 5. Wading birds have elevated mercury levels.

Mercury Contamination

Many of South Florida's fresh waters are under human health fish consumption advisories because of mercury contamination in largemouth bass and other top predator fish. Mercury concentrations in an endangered Florida panther were high enough to either have killed or contributed to the death of that panther in 1989 (Figure 4). Wading bird populations today are about one-fifth of their abundance in the 1930s. Wading bird mercury concentrations also are high in certain Everglades areas, one of many factors that might be contributing to their decline (Figure 5). The sources and factors contributing to this mercury contamination and bioaccumulation are not yet clearly understood. If the sources or critical processes can be identified, understood, and managed, the effects of mercury contamination may be reversible. This reversal, however, could take decades to realize even with effective management practices.

Habitat Alteration and Loss

Figure 6. Urban development has altered water flow and habitat.

Over 1 million acres of the original River of Grass have been drained and altered for other uses since the turn of the 20th century (Figure 6). In addition to the habitat lost, much of the remaining habitat has been altered because of unnatural flooding and drying, ground water removal, or similar perturbations. This habitat alteration is still ongoing as the population of South Florida continues to expand. Unlike eutrophication and mercury contamination, habitat loss is irreversible with certain land uses. In addition, habitat alteration aggravates other environmental problems, and these interactions are poorly understood.

Hydropattern Modification

Figure 7. Extensive canal systems and water management have modified the natural hydropattern.

Clearly, the greatest change that has occurred in the Everglades ecosystem is due to changing the hydropattern, or the depth, timing, and distribution of surface water, that occurred naturally in these systems (Figure 7). Wetland systems, by definition, are driven by water. Canal drainage systems, levees, flood control structures, and water supply diversions have collectively contributed to large-scale changes that have occurred in the Everglades ecosystem. The US Army Corps of Engineers in their Central and Southern Florida Project Re-Study is evaluating the modification of canals and levees to return the hydropattern to a more natural regime. Determining the natural flow regime and hydropattern and subsequently implementing the required flows in the Everglades is a major restoration activity. “Draining the swamp” represents one of the greatest issues facing the Everglades ecosystem.

Endangered and Exotic Species

The South Florida ecosystem is known for its great diversity of plants and animals, many of which are endangered. Florida also has a large number of introduced or nonnative fish and birds, which compete with the native species. These introduced or exotic species are not restricted to fauna; there are also significant numbers of nonnative plants. The melaleuca tree, for example, has taken over large areas of the Everglades. This species was originally introduced because of its ability to transpire water and help drain the wetland areas. Eliminating introduced species altogether is unlikely, but practices for minimizing their impact on native habitat and preventing continued expansion into the Everglades are needed.

Interaction Among Issues

None of the issues discussed above are independent of the others. These issues are all intertwined, each problem affecting other problems. Addressing these issues requires a large-scale perspective. Integrated and holistic studies of the multiple issues impacting the Everglades need to compare the risks associated with all impacts and their interactions. The US EPA South Florida Ecosystem Assessment effort is a project that provides a foundation for addressing these issues and contributes to the InterAgency Task Force on Ecosystem Restoration efforts.

> The greatest threat to the Everglades ecosystem is to assume the issues are independent.

Ecosystem Restoration

Among the federal and state Everglades restoration efforts in progress are the EAA phosphorus control program and projects to restore water delivery (and ecology) throughout the Everglades. The present US EPA South Florida Ecosystem Assessment effort integrates several important restoration issues and provides a critical science-based foundation for ecosystem assessment and restoration. Long-term monitoring will provide critical baseline information to evaluate ecosystem restoration. More importantly, continued monitoring is the only way to evaluate the effectiveness of management strategies to improve ecological conditions.

US EPA REGION 4 SOUTH FLORIDA ECOSYSTEM ASSESSMENT PROJECT

The US EPA Region 4 Regional Environmental Monitoring and Assessment Program (REMAP) is an innovative, long-term research, monitoring and assessment program designed to measure the current and changing condition of ecological resources in South Florida. The ultimate goal of this program is to provide decision makers with sound ecological data to improve environmental management decisions on multiple environmental issues and restoration efforts. The Region 4 South Florida Ecosystem Assessment Project uses the US EPA ecological risk assessment framework as a foundation for providing decision makers with critical information (Figure 8). The program is guided by seven policy-relevant questions:

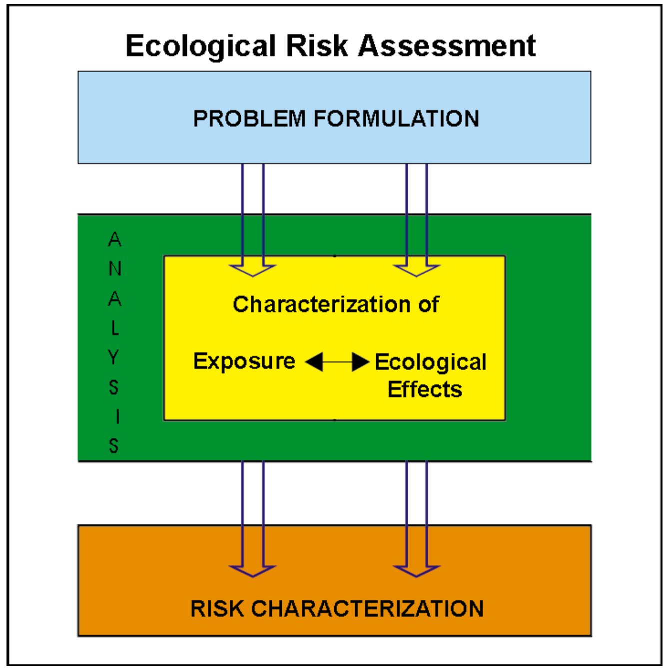


Figure 8. Ecological Risk Assessment Framework. Ecological risk assessment is a way of determining the likelihood of adverse ecological effects from a pollutant or management practice.

(1) Magnitude - What is the magnitude of the mercury problem?
(2) Extent - What is the extent of the mercury problem?
(3) Trend - Is the problem getting better, worse, or staying the same?
(4) Cause - What factors are associated with or causing the problem?
(5) Source - What are the contributions and importance of mercury from different sources?
(6) Risk - What are the risks to different ecological systems and species from mercury contamination?
(7) Solutions - What management alternatives are available to ameliorate or eliminate the mercury contamination problem?

*Probability Samples: Foundation For Regional Risk Assessment

Probability samples are samples where every member of the statistical population has a known chance of being selected and where the samples are drawn at random. The project used a statistical survey design in selecting its probability samples so that the samples were drawn in direct proportion to their occurrence in the population; whether it was EAA or WCA canals, sawgrass or cattail marshes, or soil type. The measurements taken can be used to estimate the proportion (extent) and condition of that resource in South Florida. The probability of selecting the site is known and the site represents that resource in an unbiased manner. The sampling design is not biased to favor one marsh type over another (e.g., sampling only the marshes next to a road because it was easier, or selecting a canal because it looked good or bad). The risk to any of the ecological resources from the multiple environmental threats in South Florida is a direct function of the extent and magnitude of both the threat and the ecological effects. Without probability samples, these risks can not be realistically estimated. Probability samples provide the foundation for ecological risk assessment in South Florida.

The seven questions listed are equally applicable to each issue impacting the Everglades ecosystem, such as mercury contamination, eutrophication, habitat alteration, or hydropattern modification.

The Region 4 project used a random, probability-based sampling strategy to select sites for sampling *. Samples were collected from south of Lake Okeechobee to the mangrove fringe on Florida Bay and from the ridge along the eastern coast into Big Cypress National Preserve on the west. The distribution of 200 canal samples is shown in Figure 9 while the distribution of 500 marsh samples is shown in Figure 10. The samples represent the current ecological condition in over 750 miles of canals and in over 3000 square miles of marsh (over 2 million acres). The canals were sampled in September 1993, May and September 1994, and May 1995. The marshes were sampled in April and September 1995 and May and September 1996. This corresponds to two dry (April and May) and two wet (September) seasons for both systems over a two-year period. The project sampling included water (Figure 11), canal sediment, marsh soil (Figure 12), fish (Figure 13), and algae at each canal and marsh sampling site location during each sampling period. The parameters

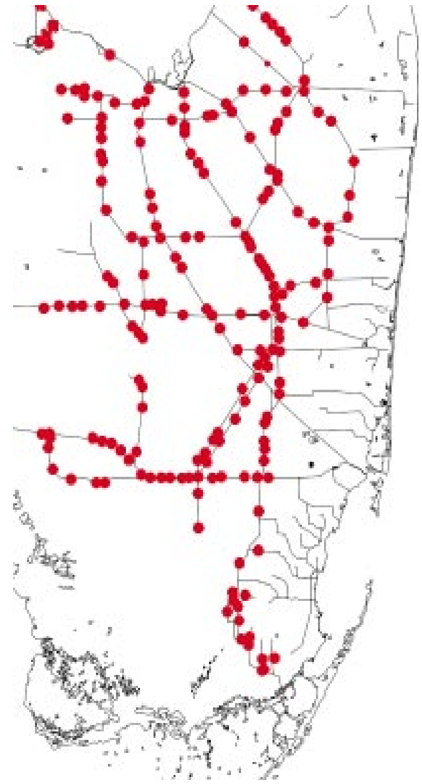


Figure 9. 200 sampling sites are located on over 750 canal miles.

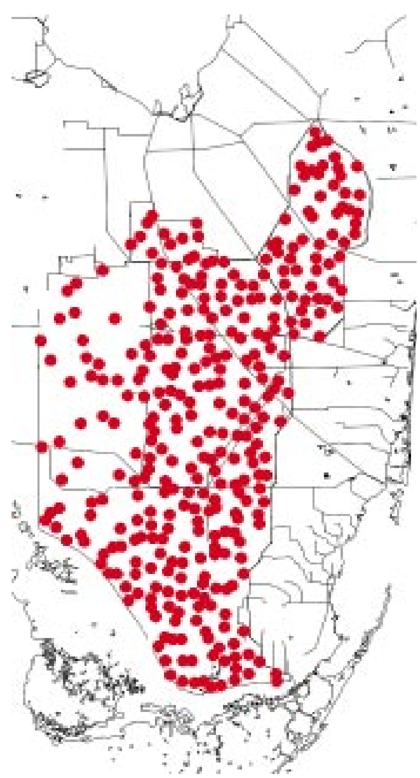


Figure 10. 500 sampling sites are located on over 2 million marsh acres.

that were measured at each site can be used to answer questions on multiple issues, including

- Eutrophication (e.g., Total phosphorus, cattail, sawgrass, and periphyton distribution)
- Mercury contamination (e.g., mercury in water, soil, algae, and mosquitofish)
- Habitat alteration (e.g., plant community distributions throughout South Florida)
- Hydropattern modification (e.g., water depth at all sites)

Figure 11. Helicopters and air boats were used for sampling the marsh.

In addition to the canal and marsh sampling, four transects established from the edge of a canal into the marsh along eutrophic gradients and the mercury load from seven canal structures were also sampled.

Figure 12. Soil cores were collected at each of the marsh sites and analyzed for mercury, nutrients, and other constituents.

The study is providing information critical to the South Florida Ecosystem Restoration Task Force. The project is providing information to answer the policy-relevant questions raised above and to determine if the precursor and ecological success criteria identified by the Task Force are being achieved.

Figure 13. Mosquitofish were sampled because they are common in both the canals and the marsh.

This study permits a synoptic look at the ecological condition of the entire freshwater canal and marsh system in South Florida from Lake Okeechobee to the Florida mangrove systems. This large-scale perspective is needed to understand the impacts of different factors, such as phosphorus, mercury, habitat alteration, or hydropattern modification, on the entire system rather than a small piece or area. Looking only at isolated pieces in any given area and extrapolating to South Florida would provide a distorted perspective. The statistical sampling approach permits

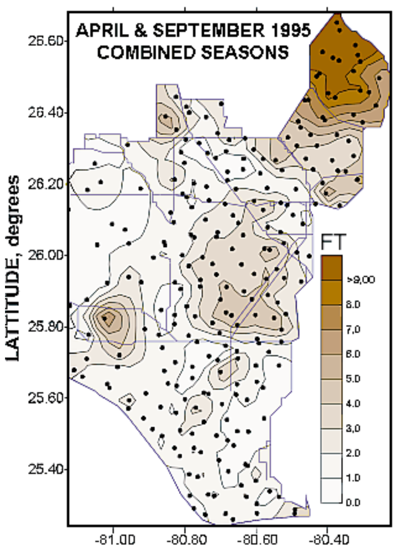


Figure 14. Thickness of the soil or peat deposits throughout the marsh.

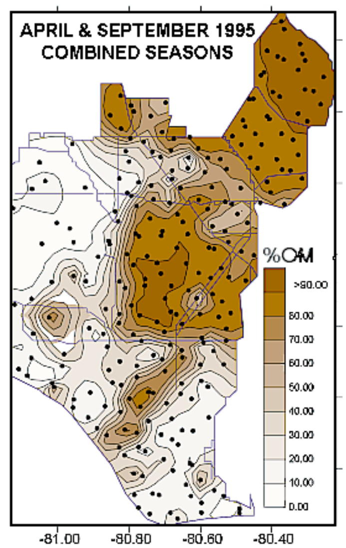


Figure 15. Percent Organic Matter in top soil throughout the marsh.

quantitative estimates, with known confidence, about population characteristics, such as acres of marsh in cattails, percent of the marsh with fish mercury concentrations greater than the proposed predator protection level of 100 ppb (see page 14), or percent of the canal miles with total phosphorus concentrations greater than the Phase I control target level of 50 ppb. Study information is aiding decision makers with its significant findings related to the major issues facing ecosystem restoration in South Florida.

In addition to providing answers to policy relevant questions, the project also is contributing to a better scientific understanding of the Everglades ecosystem. A holistic picture of soil thickness (Figure 14) or percent organic matter (Figure 15) is not only scientifically important but also provides insight into areas with peat subsidence and areas of organic soils that might bind phosphorus or metals.

This study, while contributing to the development of adaptive management practices, also provides the information needed to evaluate the effectiveness of these management practices. For example, once the Phase I phosphorus control program is in place, phosphorus concentrations throughout the canal and marsh system can be reassessed to evaluate the effectiveness of the control program.

The following is a summary of 1993-95 study highlights based on all four canal sampling events (two wet and two dry seasons) and the first two marsh sampling events (one wet and one dry season).

Figure 16. South Florida canal water total phosphorus concentrations distributions during the wet season.

HIGHLIGHTS

EUTROPHICATION

Historically, the Everglades ecosystem was nutrient poor, with phosphorus concentrations less than 10 ppb over large areas. Increased total phosphorus concentrations and eutrophication have been associated with discharges from the Everglades Agricultural Area into the Water Conservation Areas, particularly the Refuge and Water Conservation Area 2A. In 1995 about 45% of the canal miles (about 340 miles) in both the wet and dry seasons had total phosphorus concentrations greater than the Phase I control target of 50 ppb (Figures 16 and 17). In contrast only 2% (wet season) to 5% (dry season) of the marsh area (about 39,000 to 80,000 acres) had total phosphorus concentrations in excess of 50 ppb (Figures 18 and 19). It is clear the canals are delivering total phosphorus to the marsh.

Discharging phosphorus at the Phase I control target of 50 ppb will continue to result in eutrophication of over 95% of the Everglades marshes. During the wet season, 88% of the marsh (over 1.6 million acres) has a total phosphorus concentration of less than 25 ppb, or half this target concentration, and over 35% of the marsh has a total phosphorus concentration less than 10 ppb during the wet season.

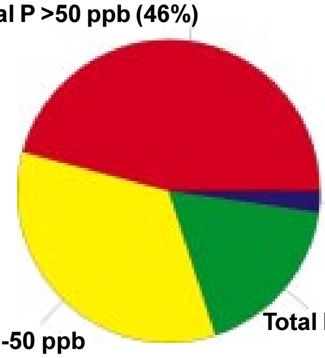


Figure 17. South Florida canal water total phosphorus concentrations distributions during the dry season.

Discharging phosphorus at the Phase I control target of 50 ppb will continue to result in eutrophication of over 95% of the Everglades marshes.

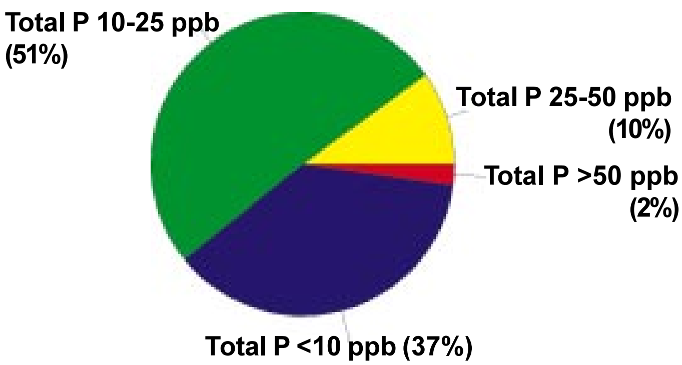


Figure 18. South Florida marsh water (area-weighted) total phosphorus concentrations distributions during the wet season.

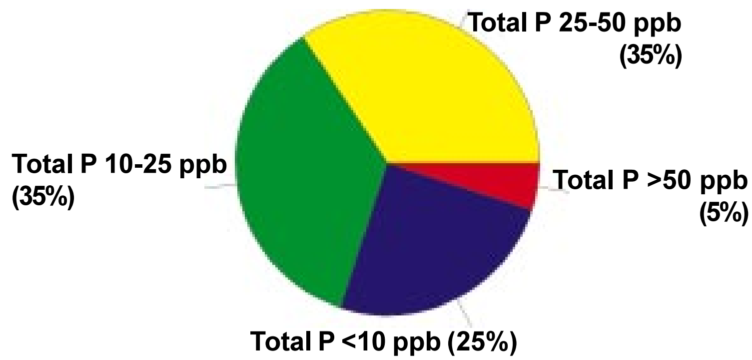


Figure 19. South Florida marsh water (area-weighted) total phosphorus concentrations distributions during the dry season.

Average total phosphorus concentrations in the canals are highest in canals north of Alligator Alley near and within the EAA (Figure 20). The average total phosphorus concentrations in the canals above Alligator Alley are about 4 times higher than in the marshes above Alligator Alley during the wet season (Figures 20 and 21). While the average total phosphorus concentrations are similar in the canals and marshes south of Tamiami Trail, delivery of total phosphorus loads from the Everglades Agricultural Area is not limited just to the marshes above Alligator Alley (Figures 20 and 21). Total phosphorus loads in the canals are being transported south into the Park (Figure 22).

These elevated nutrient concentrations are also indicated by the absence of an enzyme (alkaline phosphatase) released by micro-organisms. The enzyme is produced only when phosphorus concentrations in the water are so low that growth is limited (Figure 23). A latitudinal pattern

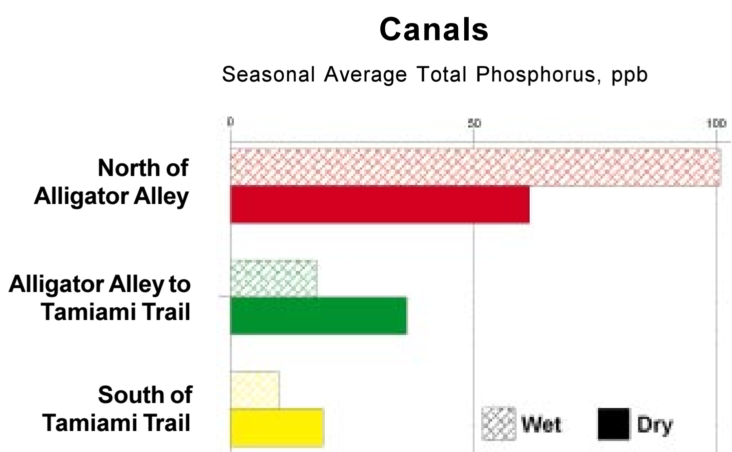


Figure 20. Water total phosphorus distribution in canals from north to south. Note: 50 ppb is the Phase I control target.

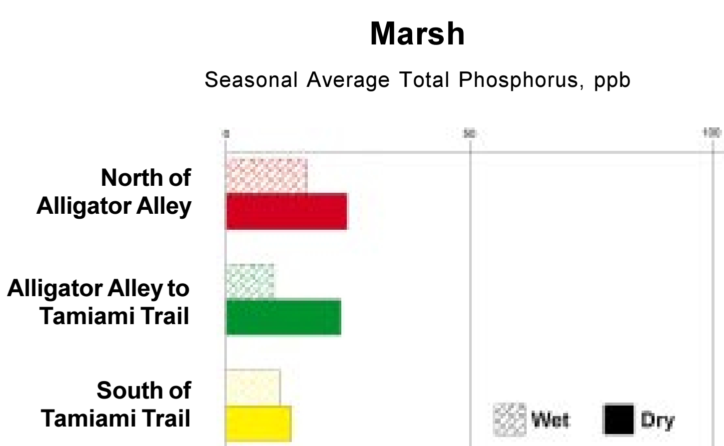


Figure 21. Water total phosphorus distribution in marsh from north to south. Note: 50 ppb is the Phase I control target.

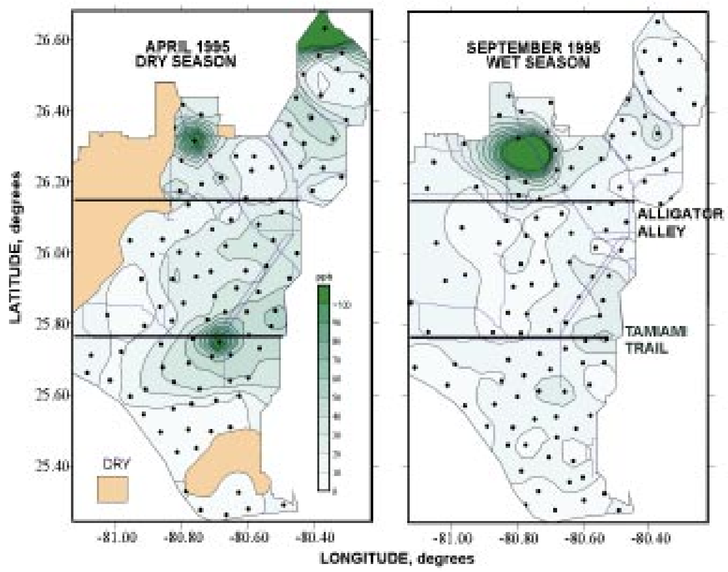


Figure 22. Pattern of marsh water total phosphorus concentrations. Note: Hot spots near EAA, the Refuge, and the Park.

exists from north to south across the marsh and also indicates the clean interior of the Refuge.

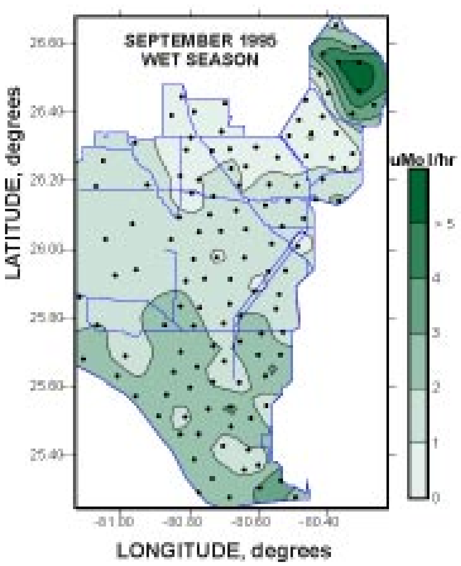


Figure 23. Microbial enzyme patterns. High enzyme values imply low phosphorus concentrations in water.

MERCURY CONTAMINATION

The REMAP program was initially designed to address mercury contamination in South Florida. Mosquitofish were selected as the indicator fish species because the fish are common throughout the marsh and canals, can be easily collected at all sampling sites, and are in the food chain for wading birds and sport fish. Largemouth bass are the popular sport fish and have high mercury concentrations, but are not found at every site, are more mobile, and are difficult to consistently collect in the marsh.

Once mercury enters the food chain, it increases in concentration or biomagnifies at each higher step or level in the food chain. The highest mercury concentrations are usually found in top predator fish (e.g., largemouth bass), birds, reptiles, and mammals

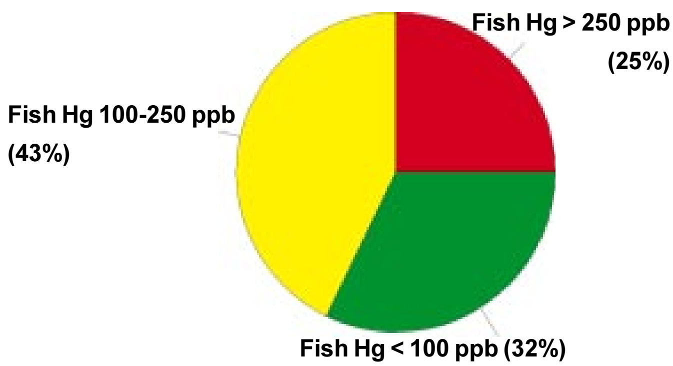


Figure 24. South Florida marsh (area-weigted) mosquitofish mercury concentration distributions.

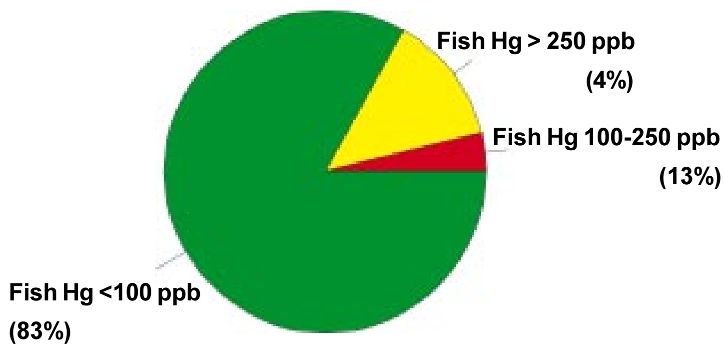


Figure 25. South Florida canal mosquitofish mercury concentration distributions.

that eat fish or fish-eating animals (e.g. raccoon, Florida panther). A predator protection level of 100 ppb mercury has been proposed by the US Fish and Wildlife Service and can be used as a criterion for comparison among systems and to determine potential exposure of largemouth bass and other fish-eating animals to mercury.

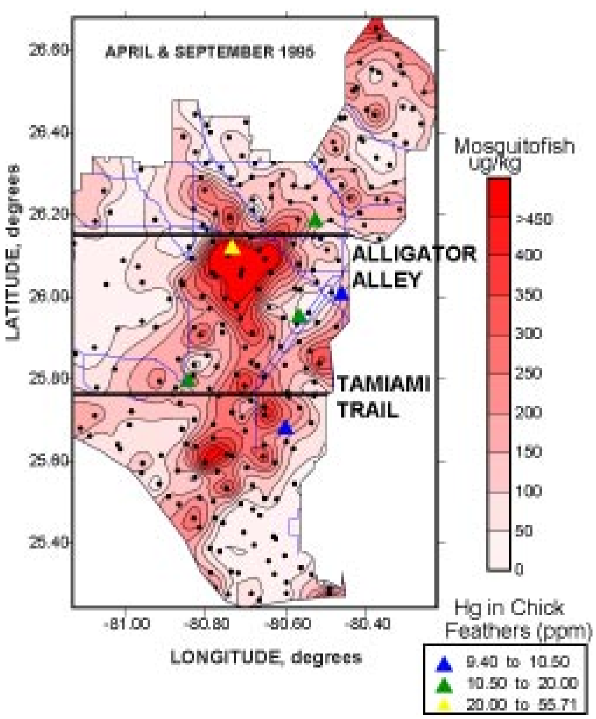


Figure 26. Hot spot is the same for total mercury in mosquitofish and great egret feathers.

In contrast to phosphorus, the highest mercury concentrations are found in the marshes and not the canals. Over half the area in the marsh (68% or over 1 million acres) has mosquitofish with mercury concentrations that exceed 100 ppb (Figure 24). About 17% of the canal miles (about 130 miles) have mosquitofish with mercury concentrations that exceed the proposed predator protection level of 100 ppb (Figure 25). The highest concentrations of methylmercury (the form of mercury concentrated in the food chain) are found not only in fish and birds (Figure 26), but also in algae in the marsh between Alligator Alley and Tamiami Trail. The concentration of mercury in marsh mosquitofish is significantly higher than the concentration found in canal mosquitofish (Figures 27 and 28).

The highest mercury concentrations in algae, fish, and Great Egrets all co-occur in Water Conservation Area 3 between Alligator Alley and Tamiami Trail.

The marshes are the primary areas of mercury contamination. For methylmercury to be formed, exactly the right combination of environmental conditions must occur. Under the right set of conditions of temperature, total phosphorus, total organic carbon, sulfate, and pH, inorganic mercury is converted by microorganisms to methylmercury. This methylmercury enters the food chain primarily through bioaccumulation by algae, bacteria, and other tiny organisms that are eaten by larger organisms. The right combination of environmental conditions occurs between Alligator Alley and Tamiami Trail (Table 1). Above Alligator Alley, the organic compounds and reduced sulfate (sulfide) might bind the mercury or methylmercury so it is not available for uptake by organisms. Below Tamiami Trail, lower concen-

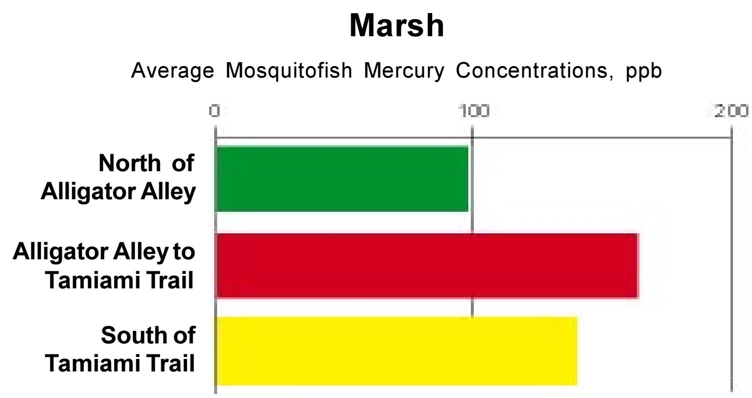


Figure 27. Marsh mosquitofish mercury distribution from north to south. Note: 100 ppb is proposed predator protection level.

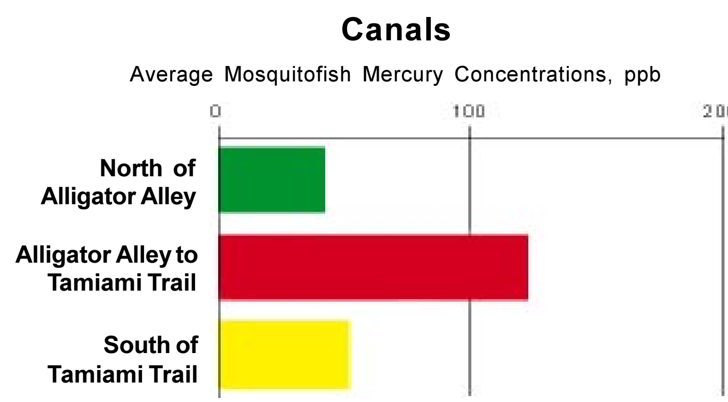


Figure 28. Canal mosquitofish mercury distribution from north to south. Note: 100 ppb is proposed predator protection level.

Table 1
Average Marsh and Canal Water Quality in Three Everglades Zones

Constituents	North of Alligator Alley		Alligator Alley to Tamiami Trail		South of Tamiami Trail	
	Marsh	Canal	Marsh	Canal	Marsh	Canal
Total Phosphorus, ppb (ug/L)	20	78	16	24	12	14
Total Organic Carbon, ppm (mg/L)	25	26	17	18	15	11
Sulfate, ppm (mg/L)	9	27	4	7	3	8
Methylmercury, ppt (ng/L)	0.6	0.2	0.4	0.2	0.2	0.1

trations of sulfate and total phosphorus are likely to limit the microbial methylation and organic production rates, respectively. Between Alligator Alley and Tamiami Trail, the concentrations of organic compounds and sulfide have decreased and probably no longer compete with the microorganisms for mercury. In addition, phosphorus delivered from the canals to the marsh in low concentrations may stimulate the growth of periphyton mats. Periphyton are attached algae common in the Everglades ecosystems. The USGS has found methylating bacteria associated with these mats.

Increased production of algal mats may result in increased methylmercury production. This methylmercury then increases in the food chain from algae up to wading bird nestlings and higher food chain levels. The highest bioaccumulation in mosquitofish occurs between Alligator Alley and Tamiami Trail in both the canal and marsh habitats (Figures 27 and 28). However, mosquitofish also have high mercury contamination in the marsh south of Tamiami Trail in the Park (Figure 27). For methylmercury to accumulate up the food chain, the right combination of environmental conditions must exist and a complete food chain for increased biomagnification at each level (Figure 29). The food chain in the canals above Alligator Alley may not be sufficiently complete to accumulate mercury to concentrations above the predator protection levels because of increased eutrophication.

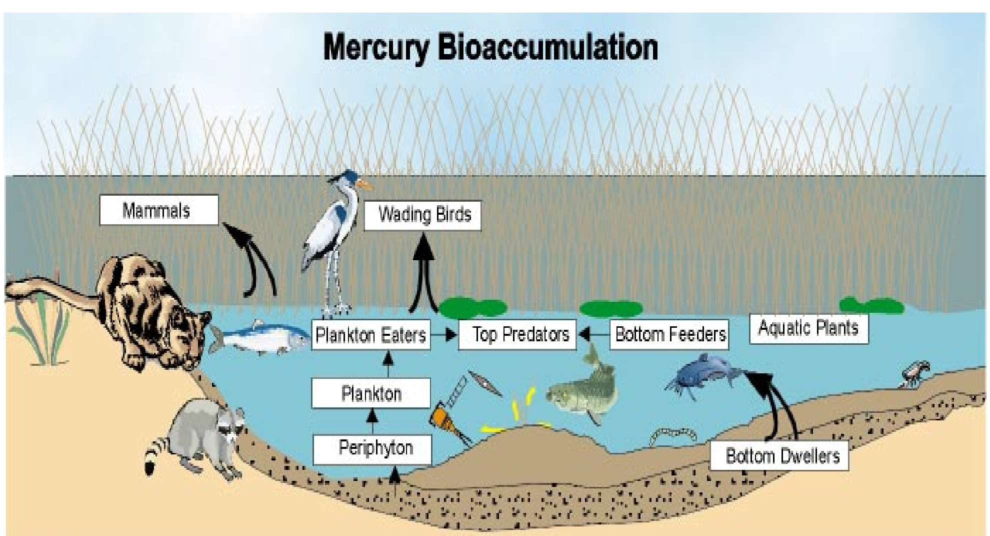


Figure 29. Bioaccumulation of mercury up the food chain from the water to wading birds and the Florida panther.

HABITAT ALTERATION

One of the greatest human impacts in South Florida has been to the natural habitat. Over 50% of the historic Everglades wetlands have been drained. In addition to habitat loss, there has also been significant alteration of the remaining habitat. Because of eutrophication, about 4% (over 77,000 acres) of the Everglades is now cattail marsh (Figure 30). At the turn of the 20th century, less than 1% of the marsh area was cattails.

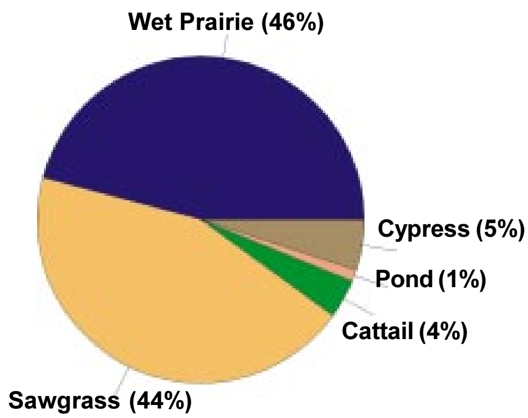


Figure 30. Current distribution of marsh types found in the South Florida Everglades.

Study results indicate that the Everglades marsh habitat (Figure 30) consists of 90% sawgrass and wet prairie communities and 4% cattail. As ecosystem restoration efforts proceed, such as phosphorus control or modifications to hydropattern, these relative habitat percentages can be monitored to assess the effectiveness of restoration efforts. Decreased percentages of cattail marsh can indicate decreased nutrient loading and decreased eutrophication. Changes in the percentages of different habitat types can also indicate an increase or decrease in the spread of exotic species, such as the melaleuca tree. There are other project habitat indicators that also provide information on other restoration issues (e.g., percent dry area).

HYDROPATTERN MODIFICATION

The greatest change that has occurred in the Everglades ecosystem is the change in surface water depth, distribution, and timing. The original intent of the canals and levees was to “drain the swamp” so it could be used for agricultural production and urban development. A comparison of a model simulation of the natural marsh water depth during a dry season for the study area is shown in contrast to the actual measured water depths in the study area in April 1995 (Figure 31). Changing water depth also can significantly impact plants and animals. Wading birds, for example, might not be able to forage because of increased depth while some fish species lose habitat because depths are too shallow. The present ponding of water in WCA-3A may influence the methylation of mercury. The cornerstone to Everglades restoration is hydrologic restoration. Without some semblance of the natural hydropattern in South Florida, the River of Grass and Big Cypress are unlikely to be protected or restored.

Ecological Restoration requires Hydropattern Restoration.

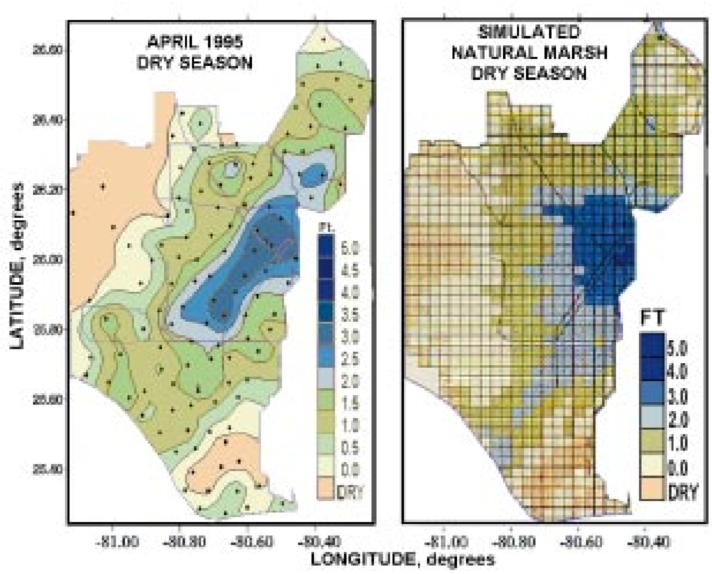


Figure 31. Comparison of current (left) vs. simulated natural marsh (right) water depths for the study area.

ECOSYSTEM RESTORATION TOOLS

Multiple tools are required to resolve multiple interrelated environmental issues. A number of tools are being used as part of the Everglades ecosystem restoration efforts, including mathematical models. To investigate the mercury contamination problem, for example, US EPA has two models that are currently available. The Marsh Screening Model (Figure 32) is a large-scale Everglades ecosystem model with relatively simple mercury cycling formulations that can be used to screen different policy and/or management scenarios and evaluate their potential effects on reducing mercury contamination. A second model, BASS, is a food chain model that provides insight on how mercury is bioaccumulated through the food chain. BASS provides insight into the potential effects of mercury on critical food chains within the Everglades ecosystem. US EPA is also developing a dynamic mercury-cycling model, MERC5.

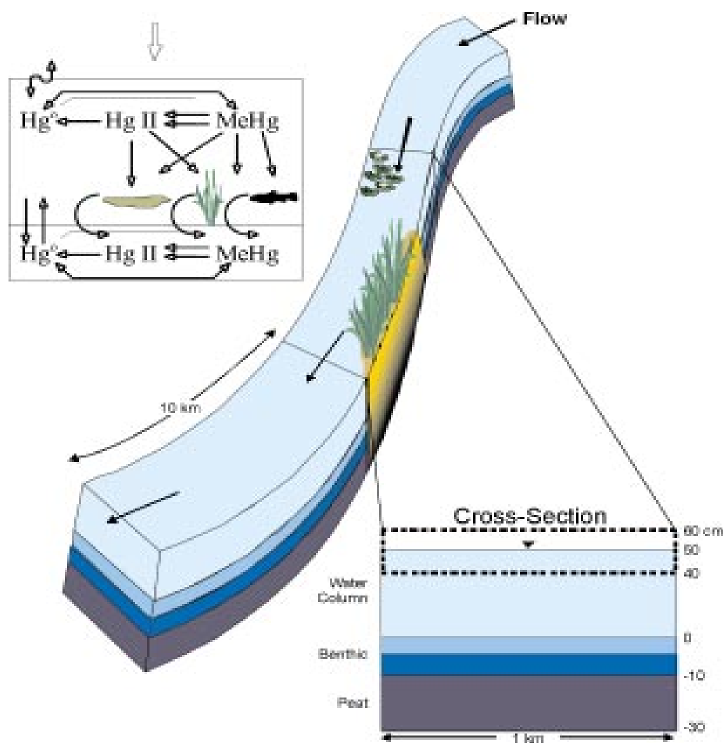


Figure 32. Schematic showing the marsh screening model network.

Other tools have been developed by other agencies and are being used to address important environmental issues, such as hydropattern modification. The South Florida Water Management District, for example, has developed several hydrologic models that are being used to evaluate different management approaches for restoring the natural hydrology to the Everglades. One of these models is called the Natural System Model. The Natural System Model provides estimates of what the hydrology might have been under various meteorological and climatic conditions before major drainage efforts began (Figure 31). A second hydrologic model simulates current conditions within the marsh ecosystem and provides a tool for

Figure 33. Waste incinerators are one of the sources of atmospheric mercury.

evaluating the effects of different flood control and water supply management options on marsh hydrology. By using both models and comparing and contrasting their output, managers can better assess which management approaches offer optimal restoration options.

Other agencies also have developed tools that are being used in the Everglades ecosystem for different issues, such as eutrophication, atmospheric emissions, habitat alteration, and other problems. While mathematical modeling is one technology that is being pursued, this is not the only set of tools in the toolbox. Improved and innovative field sampling techniques, more precise analytical procedures and use of remote sensing and satellite imagery are being used to investigate these issues. The US EPA, for example, conducted a major study to investigate mercury emissions from municipal and medical waste incinerators (Figure 33) and a coal-fired cement kiln. They are in the process of evaluating the fate and transport of this mercury and its possible deposition over the marsh (Figure 34). The State of Florida, the Electric Power Research Institute, and the US EPA established a deposition monitoring network to determine the atmospheric mercury forms and potential deposition to the marsh throughout South Florida. The USGS is conducting mercury biogeochemical and bioaccumulation process studies. Modeling, monitoring, and process studies are complementary tools for addressing Everglades ecosystem issues. All of these tools and their information must be integrated to develop management approaches that will not only restore and protect the Everglades but also satisfy the different societal demands for water supply, flood control, agriculture, and urban development.

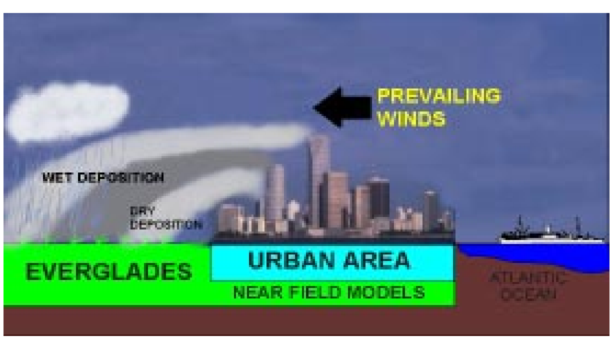


Figure 34. Fate and transport of mercury emissions from the source to the atmosphere and then deposited over the marsh.

POLICY AND MANAGEMENT IMPLICATIONS

WATER QUALITY

Mercury

The current water total mercury criterion for protection of aquatic life is 12 parts per trillion (ppt). One hundred percent of the Everglades marsh has total mercury concentrations less than 12 ppt. This criterion, therefore, is under-protective because wildlife effects have been observed and 100% of the Everglades is under a human health fish consumption advisory. In addition, the predator protection criterion for mercury in prey species of 100 ppb proposed by the US Fish and Wildlife Service is exceeded in over 65% of the marsh area. This indicates that alligators, raccoons, otters, endangered wading birds, other fish-eating animals, the Florida panther, and humans are at risk from mercury contamination.

Figure 35. Wet deposition of mercury during storms is a major source of mercury to the marsh.

The current chronic mercury aquatic life criterion is underprotective.

Mercury Loadings

South Florida Water Management District monitored total mercury concentrations biweekly at the pumps located on the canals surrounding the Everglades Agricultural Area. Atmospheric deposition monitoring data were collected at seven locations throughout South Florida. The data from these two monitoring programs were used to estimate the annual total mercury loads to the Everglades ecosystem (Table 2). Atmospheric deposition in precipitation (Figure 35) contributed from 35 to 70 times the mercury loading to the fresh water Everglades compared to Everglades Agricultural Area stormwater. It is not known what proportion of this atmospheric deposition is of natural versus anthropogenic origin. Atmospheric mercury source apportionment studies are scheduled for the next 4 to 5 years.

Table 2
Comparison of Atmospheric vs. Surface Water Mercury Loading

Year	Atmospheric Deposition (Kg/yr)	EAA Water Discharge (Kg/yr)
1994	140	2
1995	140	3-4

Figure 36. EAA stormwater discharge contributes nutrients and mercury.

Phosphorus

The Phase I interim phosphorus control target has been established at a maximum of 50 ppb. However in 1995, 97% of the marsh had total phosphorus concentrations less than 50 ppb. In addition, over 88% of the marsh had total phosphorus concentrations less than 25 ppb or half the Phase I total phosphorus control target. Discharges from the Stormwater Treatment Areas at 50 ppb will continue to increase Everglades eutrophication (Figure 36).

Discharges from the Stormwater Treatment Areas at 50 ppb will continue to cause Everglades eutrophication.

Phosphorus-Mercury Interactions

The increased phosphorus concentrations measured in the Refuge, the Everglades Water Conservation Areas, and the Park are above natural background concentrations and may aggravate the mercury problem by increasing the biomass of the periphyton mats in which additional mercury methylation might be occurring. Recent studies by the USGS have indicated that periphyton mats and associated microbial communities might serve as methylation sites for mercury. Because the historic Everglades were so nutrient-poor, there is a clear relationship between increased phosphorus and eutrophication, which can result in increased plant biomass, including periphyton. The effects of increased phosphorus cascade through the ecosystem affecting more than just plant biomass. When production exceeds some critical threshold, organic matter can bind mercury, making less mercury available for methylation. In addition, if oxygen concentrations go to zero because of decaying organic matter, sulfide can be released that also binds mercury. Process and food web studies are required to further define the driving factors and associated environmental conditions.

AIR QUALITY

Based on the deposition monitoring (Figure 37), emission studies, and an emissions inventory, the average mercury emissions for South Florida are about 3 times higher than the state average. In South Florida, the mercury deposition from precipitation downwind of the urban area is about 2 to 3 times the background level. The emission source studies indicate that municipal and medical waste incinerators are the major atmospheric mercury emission sources in South Florida. The portion of deposited mercury that comes from local sources has not been determined. However, additional studies to provide better estimates of natural mercury releases to the atmosphere are in progress.

Figure 37. Air deposition monitoring towers are located at 7 sites throughout South Florida.

Incineration, not natural sources, is the primary source of atmospheric mercury in South Florida.

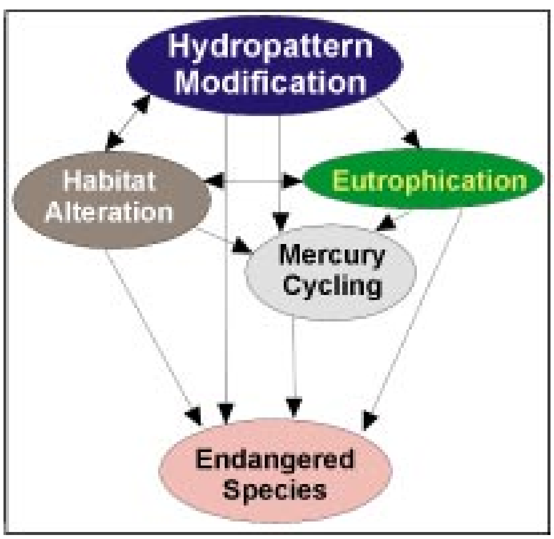


Figure 38. Restoration issues are highly interdependent and must be addressed together.

ASSESSING THE RISK

US EPA Region 4 is in the process of conducting a comparative ecological risk assessment to determine which of these environmental problems place the Everglades ecosystem at greatest risk. The comparative assessment is critical because none of the problems occurs independently of the others (Figure 38). Hydropattern modification is a primary driver of all the problems, but hydropattern can be influenced by habitat alteration. Both of these problems influence eutrophication and mercury contamination and cycling. Eutrophication, through phosphorus addition, is apparently contributing to the mercury problem, and all of these problems influence wildlife and the increased distribution of nuisance exotic species. Assessing the risk to the ecological resources from the multiple environmental threats in South Florida requires a common reference frame for estimating the extent and magnitude of both the threat and the ecological effects. The US EPA Ecosystem Assessment Project is the first and only study, because of its sampling design and probability samples, to provide a common reference frame for multiple environmental threats and effects. The spatial patterns of soil depth, phosphorus, fish mercury, and water depth, for example, represent the first such unbiased snapshots of the condition of the South Florida Everglades ecosystem. The consistent and comparable data from this study are critical for a comparative ecological risk assessment. Continued monitoring through time will permit these comparative risk estimates to be refined, contributing to better management decisions. In addition, the Ecosystem Restoration Task Force has identified restoration success indicators (Table 3). These indicators can be built into the monitoring program and can be used to evaluate different management options for ecosystem restoration.

Table 3
Example Ecosystem Restoration Success Indicators

Problem	**Success Indicators**
Hydropattern Modification	Reinstate system-wide natural hydropatterns and sheet flow
Habitat Alteration	Increased spatial extent of wildlife corridors/greenways/flyways
Eutrophication	Reduced phosphorus loading
Mercury Contamination	Reduced top carnivore mercury body burden
Endangered Species	Increased populations of threatened/endangered species

The greatest threat to the Everglades ecosystem, however, is assuming the problems facing the Everglades can be managed independently from each other. These problems are often interdependent and must be addressed using holistic, adaptive management approaches. This forms the foundation for the comparative ecological assessment of the relative risks from each of the environmental problems.

Comparative ecological risk assessment is a critical element of adaptive management for ecosystem restoration.

ON-GOING AND FUTURE STUDIES

US EPA Region 4 has completed one full cycle of canal and marsh sampling and is in the process of analyzing the information. This information will be used not only to answer the seven policy-relevant questions (page 7) identified for mercury, but also to answer similar questions related to the other environmental problems threatening the Everglades ecosystem (Figure 39). While this information provides a sound baseline for preliminary answers to these questions, one of the wettest years on record occurred during the field sampling effort. Additional monitoring is essential to determine the variability in the baseline patterns from season to season and the effect of this variability on future management decisions. Additional monitoring will increase our ability to make statements about subareas in the Everglades ecosystem under different water management regimes and will minimize the time required to detect changes from adaptive management actions. Monitoring and iterative comparative ecological risk assessments should continue over the next 3 years as scientific understanding of the interactions among these problems develops.

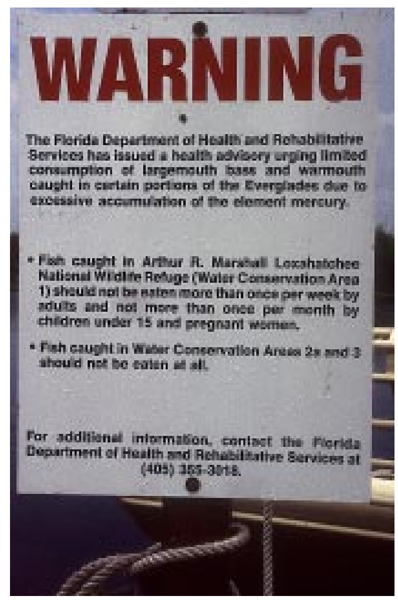


Figure 39. Fish consumption advisories apply to over 2 million acres of water in South Florida.

The US EPA Region 4 monitoring network has been redesigned based on the information collected to date. This redesign has decreased the number of samples to be collected in both canals and marshes without compromising the ability to make population estimates. In addition, this redesign will permit both canal and marsh samples to be collected during the same sampling period in dry and wet seasons each year. This monitoring will provide information on emerging trends in environmental problems and permit an evaluation of the effectiveness of any policy and management strategies implemented to fix these problems. Monitoring is the only approach that can be used to assess the success and performance of management practices.

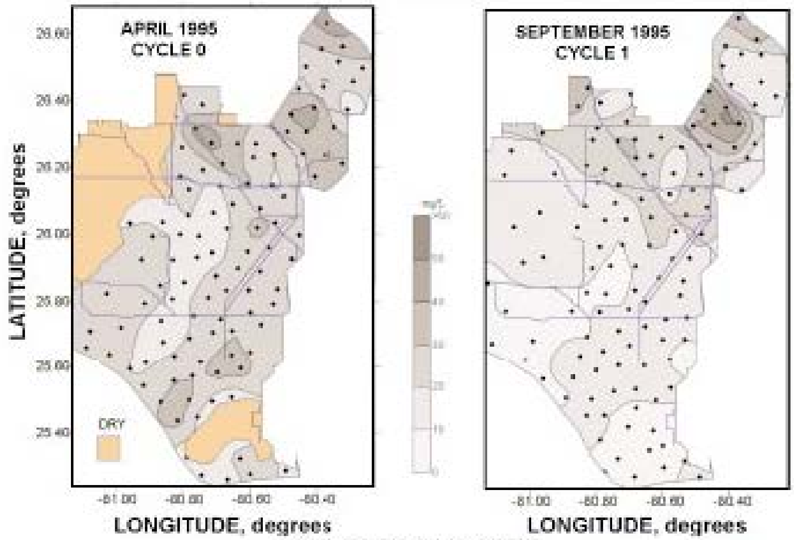
Monitoring is essential to understand the trends resulting from adaptive management practices.

The US EPA, a member of the South Florida Ecosystem Restoration Task Force, is contributing to other studies being conducted as part of the restoration effort. This project is contributing to on-going mercury biogeochemistry and bioaccumulation process studies being conducted by the USGS. For example, the Region 4 Ecosystem Assessment Project has identified critical study areas in South Florida where process research is needed to better understand the interrelationships among hydropattern modifications, nutrient additions, and mercury cycling in the Everglades ecosystems. This project is also providing complementary monitoring information for simultaneous studies of atmospheric mercury emission, transport, and deposition in South Florida. In addition, the US EPA is working with the SFWMD Everglades Nutrient Removal Project and Stormwater Treatment Area Studies, the US Army Corps of Engineers Central and Southern Florida Project Re-study, and Florida Department of Environmental Protection studies. The first comparative ecological risk assessment, incorporating results from these efforts, is planned for late 1997.

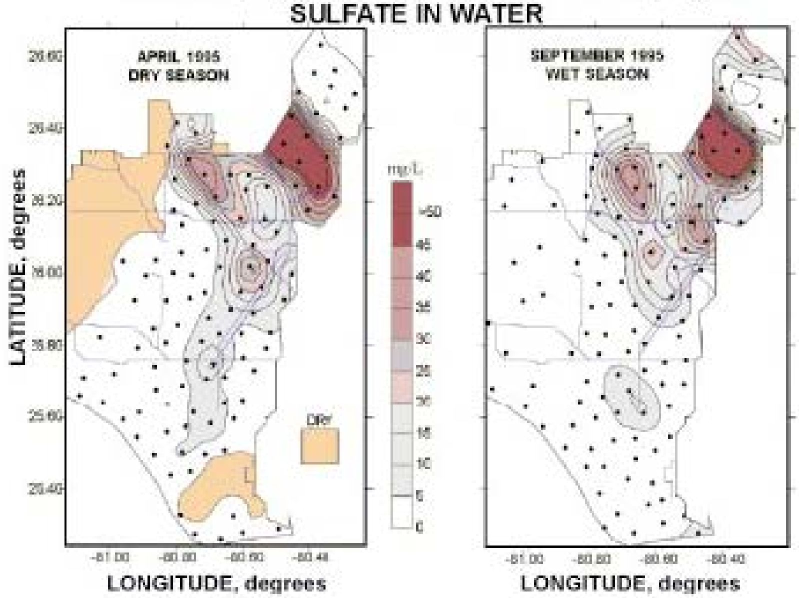
The US EPA Region 4 Ecosystem Assessment Project provides a critical framework and foundation for assessing the effectiveness of Everglades ecosystem restoration activities into the 21st century.

PATTERNS OF OTHER CONSTITUENTS

TOTAL ORGANIC CARBON IN WATER



SULFATE IN WATER



METHYLMERCURY IN WATER

METHYLMERCURY IN PERIPHYTON FLOATING