

Everglades Regional Environmental Monitoring and Assessment Program - REMAP

Water Quality and Management, Nutrients, Mercury, Soils and Habitat

Monitoring for Adaptive Management: A Phase IV Update

U. S. Environmental Protection Agency
Region 4
Water Division
Atlanta, Georgia

June 2021

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Regional Environmental Monitoring and
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REMAP**

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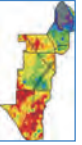


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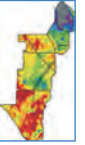
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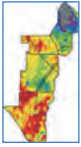
SUMMARY

The United States Environmental Protection Agency's Everglades Regional Environmental Monitoring and Assessment Program (REMAP) is a comprehensive, long-term monitoring and assessment effort. Its goal is to provide critical scientific information needed for management decisions on the Everglades ecosystem and its restoration. Since 1993, four phases of marsh sampling and one phase of canal sampling have been conducted throughout the Everglades landscape at 1250 different locations. REMAP is unique to the Everglades in consistently combining several aspects of scientific study: a probability-based sampling design which results in quantitative statements across space about the condition of the Everglades; multi-media sampling; and extensive spatial coverage that includes all of the freshwater Everglades.

Everglades REMAP:

- contributes to understanding the effectiveness of phosphorus control efforts;
- contributes to the joint federal-state Comprehensive Everglades Restoration Plan (CERP) by quantifying conditions in three physiographic regions: Everglades ridge and slough; Everglades 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 and the effectiveness of restoration efforts can be measured;
- 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 many applications:
 - document water conditions, soil thickness and subsidence;
 - document landscape patterns of water quality conditions and soil nutrients and contaminants;
 - understand water management impacts on water quality;
 - determine which portions of the Everglades are phosphorus-impacted;
 - understand sulfur sources and distribution;
 - document mercury conditions, landscape patterns, mass balances, biomagnification factors and identify environmental conditions associated with high mercury in prey fish;
 - map vegetation and determine vegetation classes, biomass, standing stocks and presence of exotic species;
 - determine landscape patterns of periphyton;
 - and understand spatial variation in aquatic food webs.

This report summarizes results for REMAP's September 2014 wet season Phase IV biogeochemical sampling, which documented conditions during a two-week sampling snapshot throughout the 2,098-square-mile freshwater portion of the Everglades. The 2014 conditions are also compared to the conditions observed by REMAP during the 1990s and 2005.



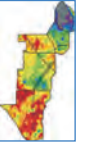
Key findings:

• **Less phosphorus enrichment and improved phosphorus conditions:** Surface water phosphorus was lower in 2014 as compared to 2005. During 2014, $14.8 \pm 4.8\%$ of the Everglades marsh had a surface water phosphorus concentration greater than 10 parts per billion, as compared to $27.2 \pm 7.5\%$ in 2005. This improvement is due to the combination of agricultural best management practices and Florida's Stormwater Treatment Areas. REMAP data also indicate no change in soil phosphorus conditions in 2014 compared to 2005. During 2014, $21.1 \pm 5.6\%$ of the Everglades had soil phosphorus exceeding 500 milligrams per kilogram (mg/kg), Florida's definition of "impacted", as compared to $24.5 \pm 6.4\%$ in 2005. REMAP previously found that the area with soil phosphorus >500 mg/kg expanded from the 1990s to 2005.

• **Mercury was lower in mosquitofish and water, but was still elevated:** The mercury concentration in mosquitofish was lower during the 2014 REMAP wet season sampling event, as compared to 2005 and 1995. Mosquitofish are a key food item for other fish, which then are consumed by Everglades gamefish as well as wading birds. Therefore, mosquitofish are relevant to human health and ecological health. During the 2014 wet season, $13.0 \pm 5.7\%$ of the marsh had mosquitofish that exceeded 77 parts per billion, the maximum concentration USEPA recommends in trophic level 3 fish as being protective of top predators such as birds and mammals, in contrast to $64.7 \pm 7.3\%$ in 2005 and $70.5 \pm 7.1\%$ in 1995. Concentrations of methylmercury and total mercury in surface water were also lower in 2014 than in 2005. The biomagnification of methylmercury from surface water to mosquitofish continues to be high. Florida's fish consumption advisories for gamefish to protect human health are still in effect.

• **No further indication of soil loss in the public Everglades:** There was no indication of further soil loss overall in the Everglades in 2014 as compared to 2005 and 1995-96. REMAP 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 were subjected to drier conditions. An inch of peat soil that took centuries to form can be lost within a few years, or within hours if dry soils are subjected to fire. In 2014, about 25% of the greater Everglades had 1.0 feet or less of soil, as did 52% of Everglades National Park. The median soil thickness in the Everglades was 2.3 feet. The volume of soil remaining in the Everglades was 4.7×10^9 cubic meters. Water management structural and operational changes would help to maintain the remaining marsh soils in drier areas, along with the plant communities and wildlife habitats of these wetlands. The northern portion of WCA3 must dry out less frequently if further soil loss is to be prevented. This is a focus of the Central Everglades Planning Project.

• **Pronounced water quality gradients:** There are pronounced spatial gradients in surface water sulfate, chloride, specific conductance, carbon, nitrogen and phosphorus in the Everglades marsh. These gradients are due to the relative contribution of rainwater, stormwater and groundwater and the proximity to canals. The highest concentrations typically occur during the wet season in WCA2, due to its proximity to the Everglades Agricultural Area and stormwater discharges. Concentrations generally decrease to natural background levels as water moves downstream through the Everglades. Years with higher discharge tend to have higher concentrations. Location, time of year, rainfall and water management practices are important factors that affect water quality.



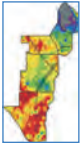
• **Canals are a conduit for transport of degraded water:** The canal system, constructed primarily for flood control and water supply, is an inadvertent conduit for the transport of degraded water with elevated sulfate, chloride, specific conductance, carbon, phosphorus and nitrogen into the Everglades marsh. Water management practices affect water quality. Downstream water quality could be improved if canals were eliminated, or if they were operated to minimize the influence of canal flow and maximize the sheet flow of marsh surface water, with the diluting influence of rainfall and cleaner marsh water, as is proposed by various restoration efforts. Regardless, pollutant control is usually most effective at the source.

• **Sulfate was lower in surface water:** Surface water sulfate was lower during the 2014 REMAP wet season sampling event, as compared to 2005 and 1995. In 2014, about $37.1 \pm 6.0\%$ of the Everglades marsh had a surface water sulfate concentration exceeding 1.0 parts per million (ppm), the Everglades restoration goal, as compared to $57.3 \pm 6.0\%$ in 2005. Interior portions of the Everglades, distant from stormwater discharges from the Everglades Agricultural Area, had concentrations as low as 0.02 milligrams per liter, although some elevated concentrations were still found as far south as Shark River Slough within the Park.

• **Water quality and soil conditions vary by location and time:** Water quality conditions in the Everglades vary greatly with location. Rainfall-driven areas that are distant from the influence of canal water, such as the interior of the Refuge and the southwest portion of WCA3, have good water quality and low soil phosphorus. The interior of the Refuge tends to have good water quality and the lowest phosphorus concentrations observed in peat soils. In contrast, northern WCA3 has thinner soil because of drainage, elevated soil phosphorus, and extensive cattail encroachment. WCA2 has phosphorus enrichment and cattail encroachment, along with higher surface water sulfate, chloride, conductivity, nitrogen and organic carbon. Water depth at any given location varies with season and year.

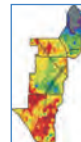
• **Environmental threats are interrelated:** Environmental stresses such as water management, soil loss, water quality degradation, cattail expansion, and mercury contamination are often interrelated. Efforts to manage water quantity and restore the Everglades should be integrated with efforts to manage or control phosphorus, mercury and sulfur. Management and restoration options should be assessed from a holistic perspective.

For three decades beginning in the 1990s, Everglades REMAP has provided monitoring and assessment data for measuring ecosystem health and the effectiveness of Everglades restoration. As CERP restoration efforts and Everglades phosphorus and mercury control efforts proceed, this probability-based sampling can be repeated to quantitatively document the condition of the Everglades and the effectiveness of these efforts. This report describes the condition of the Everglades during the intensive 2014 marsh sampling effort. All REMAP data and reports are available at: <https://www.epa.gov/everglades/environmental-monitoring-everglades>.

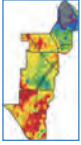


ABBREVIATIONS

cc = cubic centimeters, cm^3
cm = centimeters
ft = feet
g = grams
g/cc = grams per cubic centimeter
in = inches
km = kilometers
lbs/ac = pounds per acre
n = number or count
ppb = parts per billion ($\mu\text{g/L}$)
ppm = parts per million (mg/L) or (mg/kg)
mg/kg = milligrams per kilogram (parts per million, ppm)
mg/L = milligrams per liter (parts per million, ppm)
ng/g = nanograms per gram (parts per billion, ppb)
ng/L = nanograms per liter (parts per trillion, ppt)
 $\mu\text{g/cc}$ = micrograms per cubic centimeter
 $\mu\text{g/g}$ = micrograms per gram (parts per million, ppm)
 $\mu\text{g/kg}$ = micrograms per kilogram (parts per billion, ppb)
 μM = micromolar = 1 micromole per liter ($\mu\text{mol/L}$)
 $\mu\text{mhos/cm}$ = micromhos per centimeter
AA = Alligator Alley (Interstate 75)
ASR = Aquifer Storage and Recovery
BCFm = Bioconcentration Factor
BCNP = Big Cypress National Preserve
BMPs = Best Management Practices
CD = Consent Decree
CDF = Cumulative Distribution Function
CERP = Comprehensive Everglades Restoration Plan
CEPP = Central Everglades Planning Project
CI = Confidence Interval
DO = Dissolved Oxygen
DOC = Dissolved Organic Carbon
DOM = Dissolved Organic Matter
EAA = Everglades Agricultural Area
ECP = Everglades Construction Project
EDEN = Everglades Depth Estimation Network
EFA = Everglades Forever Act
ENP = Everglades National Park
EMAP = Environmental Monitoring and Assessment Program
EMM = Eastern Marl Marsh; E = East; W = West
EPA = Everglades Protection Area
FDEP = Florida Department of Environmental Protection
FDHRS = Florida Department of Health and Rehabilitative Services
FDOH = Florida Department of Health
FIU = Florida International University
FWM = Flow-Weighted Mean
GIS = Geographic Information System
I-75 = Interstate 75 (Alligator Alley)



LNWR = Arthur R. Marshall Loxahatchee National Wildlife Refuge
LSASD = USEPA Region 4 Laboratory Services and Applied Science Division
MDL = Method Detection Limit
MeHg = Methylmercury
N = Nitrogen
NADP = National Atmospheric Deposition Program
NRC = National Research Council
NESS = Northeast Shark Slough
OFW = Outstanding Florida Water
OMM = Ochopee Marl Marsh
P = Phosphorus
Park = Everglades National Park
QA = Quality Assurance
QAPP = Quality Assurance Project Plan
RECOVER = Restoration Coordination and Verification
Refuge = Arthur R. Marshall Loxahatchee National Wildlife Refuge
REMAP = Regional Environmental Monitoring and Assessment Program
S = Sulfur
SESD = USEPA Region 4 Science and Ecosystem Support Division
SRS = Shark River Slough
SFWMD = South Florida Water Management District
SSAC = Site-Specific Alternative Criterion
STA = Stormwater Treatment Area
THg = Total Mercury
TOC = Total Organic Carbon
TMDL = Total Maximum Daily Load
TN = Total Nitrogen
TP = Total Phosphorus
TS = Taylor Slough
USACE = United States Army Corps of Engineers
USDOI = United States Department of Interior
USEPA = United States Environmental Protection Agency
USFWS = United States Fish and Wildlife Service
USGS = United States Geological Survey
WCA = Everglades Water Conservation Area 2A, 2B, 3A, 3B; 3AN = WCA 3A north of I-75; 3AS = WCA 3A south of I-75
WY = Water Year, May to April (e.g., WY 16 is May 1, 2015 to April 30, 2016)



ACKNOWLEDGMENTS

The United States Environmental Protection Agency's Regional Environmental Monitoring and Assessment Program (REMAP) is a comprehensive, long-term monitoring and assessment effort. Its goal is to provide critical scientific information needed for management decisions on the Everglades ecosystem and its restoration. This large undertaking would not have been possible without the efforts and collaborative support of many people. The United States Department of Interior and Everglades National Park provided helicopter operations support. Sampling permits or access were received from the Miccosukee Tribe of Indians of Florida, the Arthur R. Marshall Loxahatchee National Wildlife Refuge, Big Cypress National Preserve and Everglades National Park. This report was reviewed by USEPA scientists and program experts (Chris Decker, Susan Dye, Morris Flexner, Cecelia Harper, Michele Wetherington). This report benefited from peer reviews provided by scientists at the South Florida Water Management District (Dr. Binhe Gu, Dr. Nenad Iricanin, Dr. Susan Newman, Dr. Fred Sklar), Florida Department of Environmental Protection (Dr. Paul Julian), Arthur R. Marshall Loxahatchee National Wildlife Refuge (Dr. Rebekah Gibble, Rolf Olson), United States Army Corps of Engineers (Dr. Gretchen Ehlinger), and the United States Geological Survey (Dr. Nicholas Aumen, Dr. David Krabbenhoft, Dr. William Orem).

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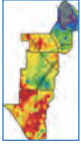
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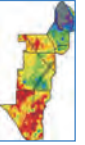
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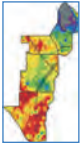
INTRODUCTION AND PURPOSE

The United States Environmental Protection Agency (USEPA) Everglades Regional Environmental Monitoring and Assessment Program (REMAP; Program) is a unique, long-term, monitoring, assessment and research effort. Its goal is to provide scientific information that is needed for decisions about the protection, restoration and management of the Everglades ecosystem. REMAP data have been used by over 30 entities including federal and state agencies, Indian Tribes, agriculture, the public, non-governmental organizations, and the National Academies of Sciences to document conditions and determine whether they are improving, are unchanged, or are worsening. Data also help to assess restoration progress and understand the effectiveness of control programs for phosphorus and mercury. Since 1993, one phase of canal sampling and four phases of marsh sampling have been conducted throughout the Everglades landscape at 1250 sampling locations (Figures 1 and 2).

The purpose of this report is to document conditions in the Everglades during 2014, the fourth phase of marsh sampling, and make statements about whether conditions in the Everglades were better, unchanged, or worse compared to 1995 and 2005. REMAP is unique to the Everglades in that it consistently combines several aspects of scientific study - a probability-based sampling design which results in quantitative statements across space about the condition of the Everglades, multi-media sampling (water, soil, biota) and an extensive spatial coverage that includes all of the freshwater Everglades.



Figure 1. Everglades wet prairie and sawgrass marsh mosaic. Tree islands are visible on the horizon. Numerous environmental issues threaten the Everglades “River of Grass,” such as water management, soil loss, water quality degradation, and habitat alteration.



Goal: Provide environmental information that contributes to environmental management decisions on Everglades protection and restoration.

Everglades REMAP:

- documented pre-restoration conditions in the Everglades during the 1990s, as well as conditions during more recent decades after initiation of restoration efforts;
- contributes to understanding 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 (Figures 1 and 2); Everglades marl prairie/rocky glades; and Big Cypress Swamp;
- provides information on four groups of Everglades restoration success indicators (media): surface water, soil and sediment, vegetation, and fish;
- simultaneously assesses the effects and potential risks of multiple environmental stressors on the Everglades ecosystem, such as water management, soil loss, water quality degradation, nutrient enrichment, habitat loss, and mercury contamination;
- permits spatial analyses and identifying associations that provide insight into relationships among environmental stressors and observed ecological responses; and
- provides data with many applications:
 - document water conditions, soil thickness and subsidence;
 - document landscape patterns of water quality conditions and soil nutrients and contaminants;
 - understand water management impacts on water quality;
 - determine which portions of the Everglades are phosphorus-impacted;
 - understand sulfur sources and distribution;
 - document mercury conditions, landscape patterns, mass balances, biomagnification factors and identify environmental conditions associated with high mercury in prey fish;
 - map vegetation and determine vegetation classes, biomass, standing stocks and presence of exotic species;
 - determine landscape patterns of periphyton;
 - understand spatial variation in aquatic food webs.

REMAP has been carried out in cooperation and coordination with the United States Fish and Wildlife Service, National Park Service, Florida Department of Environmental Protection, United States Army Corps of Engineers, Miccosukee Tribe of Indians of Florida, Seminole Tribe of Indians, Florida International University, United States Geological Survey, and the South Florida Water Management District.

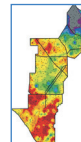
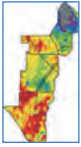


Figure 2. The Everglades marsh sawgrass and open water mosaic: ground view (top) and aerial view (bottom).

For three decades beginning in the 1990s, Everglades REMAP has provided monitoring and assessment data for measuring ecosystem health and the effectiveness of Everglades restoration. As CERP restoration efforts and Everglades phosphorus and mercury control efforts proceed, this probability-based sampling can be repeated to quantitatively document the condition of the Everglades and the effectiveness of these efforts. This report describes the condition of the Everglades during the intensive 2014 marsh sampling effort. All REMAP data and reports are available at <https://www.epa.gov/everglades/environmental-monitoring-everglades>.



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.

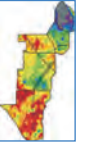
The Florida Everglades is one of the largest freshwater marshes in the world (Ramsar 2006), consisting of a unique mosaic of sawgrass, wet prairies, sloughs, and tree islands (Figures 1 and 2). Just over 100 years ago, this vast wilderness encompassed over 4,000 square miles, extending 100 miles from the shore of Lake Okeechobee south to Florida Bay. The intermingling of temperate and Caribbean flora created habitat for a variety of fauna, including alligators, Florida panthers and hundreds of thousands of wading birds. The Everglades were defined by several characteristics:

How the water flowed. Water connected the ecosystem, from north to south. Surface water flowed freely and slowly across the flat landscape. Rainfall during the wet season took months to move through the marsh. The large water storage capacity and the slow flow made wetlands and coastal waters less vulnerable to South Florida's variable and often intense rainfall (USACE and SFWMD 1999).

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 (USACE and SFWMD 1999). There was no development, so there was no need to provide flood control for agricultural or urban areas.

Diverse mosaic of landscapes. The Everglades was a complex system of plants and animals dictated in part by varied water regime - minimum, average, and maximum water depths, the duration of surface water inundation, and the slow, important flow of water that determined the ridge and slough landscape. This complex water regime resulted in diverse, expansive areas of sloughs, wet prairies, sawgrass marshes, cypress swamps, mangrove swamps, coastal lagoons and bays (USACE and SFWMD 1999).

Natural water quality conditions. Centuries ago, there were no external sources of pollutants, either from surface water or the atmosphere. There was no urban development or agriculture. Nutrients such as phosphorus and nitrogen, ions such as sulfate and chloride, and metals such as mercury all occurred at natural background levels. Clean rainfall recharged groundwater during the dry season and generated surface water, which defined soils and the natural mosaic of plant communities. There were no canals to connect groundwater and surface water, or to serve as a conduit for pollutants. The slow, shallow flow of



surface water across the landscape provided ample opportunity for cleansing by extensive wetlands. The wet prairies and sawgrass marshes of the Everglades developed under and were defined by extremely low phosphorus concentrations.

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, and across dry and wet years and occasional extreme events such as tropical storms.

An Altered System

One century ago, the greatest threat to wading bird populations was hunting (Figures 3 and 4). During the 1900s, the Everglades became an altered 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 Project for Flood Control and other Purposes (the Project) was authorized in 1948 by federal legislation. The Project's often conflicting purposes include flood control, water supply, water conservation, prevention of salt water intrusion, and preservation of fish and wildlife. The Project is one of the world's most extensive public water management systems, consisting of 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 began its design in the 1950s, about 500,000 people lived in the region and it was estimated that there might be two million people by 2000 (USACE and SFWMD 1999). The Project has effectively provided the flood control and water supply that has facilitated urban and agricultural growth and the resulting economic benefits.

Today, 50% of historic Everglades wetlands have been irreversibly drained. The Everglades ecosystem has been altered by extensive agricultural and urban development (Figures 5 to 7). South Florida's human population, which was 8.7 million in 2020 (SFWMD <https://www.sfwmd.gov/who-we-are/chairmans-message> accessed 10/30/2020), continues to increase, requiring more water and an expanding area needing flood control. This population is projected to increase to 15 million within a few decades (USACE and SFWMD 1999) (Figure 8).

The Everglades landscape changed 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), the Water



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

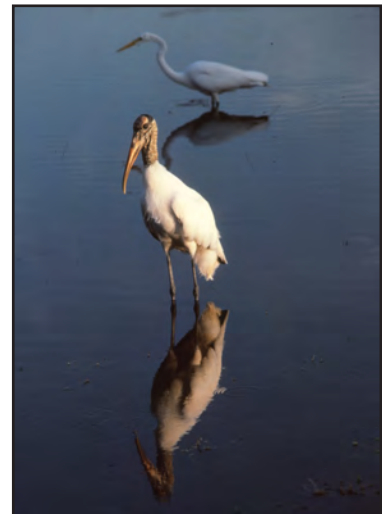
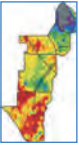


Figure 4. Everglades wading bird populations significantly declined during the 1900s. A focus of Everglades restoration is getting the water quantity, timing, distribution and quality right so wading birds can thrive.



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

Conservation Areas (WCAs), and Everglades National Park (ENP or the Park) (Figure 9). The Park, which was established in 1947, includes only one-fifth of the original “River of Grass” that once encompassed over 4,000 square miles (2 million acres) (Davis and Ogden 1994). One-fourth of the historic Everglades is in agricultural production within the 1000-square-mile Everglades Agricultural Area (EAA), where sugar cane and vegetables are grown on the rich, productive 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.

The Everglades watershed begins near Orlando 100 miles north of Lake Okeechobee. 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 and timing conflicts; loss of water storage capacity; soil loss; water quality degradation and eutrophication; unnatural changes in plant communities; habitat alteration and loss (Sklar et al. 2019); mercury contamination of game fish and wildlife such as wading birds and Florida panthers; protection of endangered species; and introduction and spread of nuisance exotic species of plants and animals.



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



Figure 6. About 400,000 acres of sugarcane are grown on the peat soils of former Everglades wetlands within the EAA.



Figure 7. Residential development on former Everglades wetlands in western Dade County, 2005.

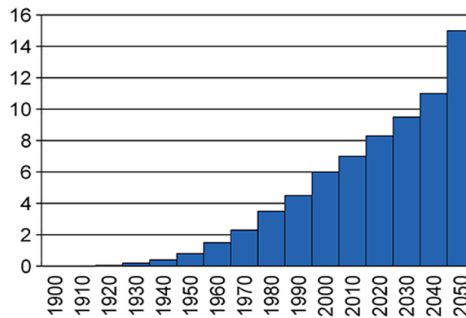


Figure 8. South Florida population in millions from 1900-2050 (USACE and SFWMD 1999 and US Census Bureau).

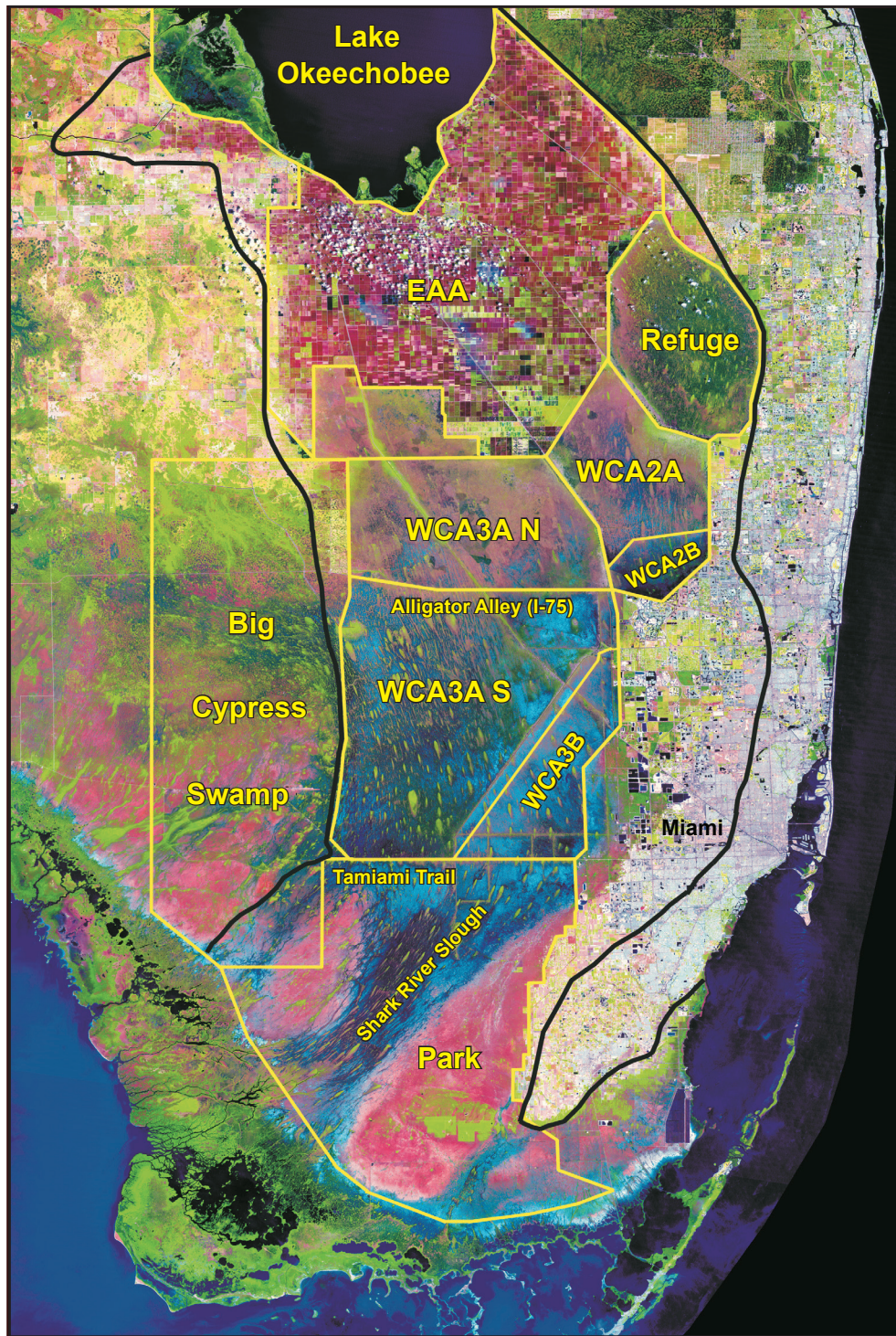
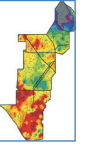


Figure 9. Satellite image of South Florida, circa 1995, with the areas sampled by REMAP outlined in yellow: Everglades Agricultural Area (EAA); Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge); Everglades Water Conservation Area 2 (WCA2A and WCA2B); Everglades Water Conservation Area 3 north of I-75 (WCA3A N); Everglades Water Conservation Area 3 south of I-75 (WCA3A S and WCA3B); the eastern portion of Big Cypress National Preserve, and the freshwater portion of Everglades National Park (Park). Light areas on the east are urban development. The black line approximates the extent of the pre-1900 Everglades marsh. The Everglades watershed begins north of Lake Okeechobee.

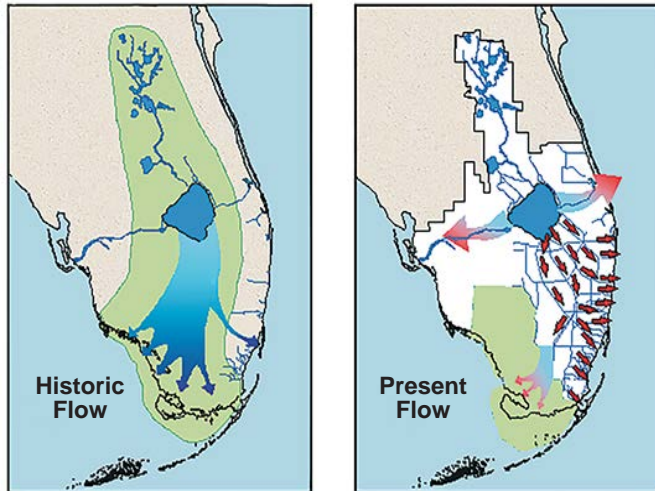
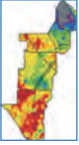


Figure 10. Historic Everglades water flow patterns (left) and present flow patterns (right) (adapted from USACE and SFWMD 1999)



Figure 11. An extensive system of canals, levees, and water control structures has modified Everglades water conditions and provides an inadvertent conduit for pollutant transport. The S9 pump station (foreground) in Broward County discharges stormwater westward from an urban basin into the Everglades (background).

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, and fostered growth. Simultaneously, the Project has altered the Everglades ecosystem. Some of the Everglades no longer receives the right quality or quantity of water at the right place or the right time. The remnant Everglades no longer exhibits the water regimes and patterns of flow, vast area, and mosaic of habitats that defined the pre-drainage, natural ecosystem. Wildlife habitat has been lost or changed, and the number of wading birds (wood stork, great egret, snowy egret, tricolored heron, and white ibis) nesting in the Everglades decreased markedly during the twentieth century (Ogden 1994). Historically, most water slowly flowed across or soaked into the region's vast wetlands. Today, over one-half of Everglades wetlands have been irreversibly drained, with the loss of their functions including water storage and water quality filtration. Flows into the Everglades marsh are at times too much or too little, and at the wrong time (Figures 9 and 10). Some areas are too wet while other areas are too dry. Overland sheet flow of water is interrupted by levees and canals that crisscross the Everglades and can provide a conduit for pollutant transport and release into the marsh (Figure 11). The canal system can quickly drain water from developed areas. Releases of nutrient-rich water from Lake Okeechobee present water quality challenges whether they flow east to the St. Lucie Estuary, west to the Caloosahatchee Estuary, or south to the Everglades. As the human population continues to increase, conflicts over water among natural resources, agriculture, industry, and a growing population may intensify.

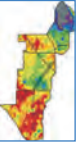


Figure 12. The right quality, quantity, timing and distribution of water are all critical to South Florida ecosystem protection and restoration.

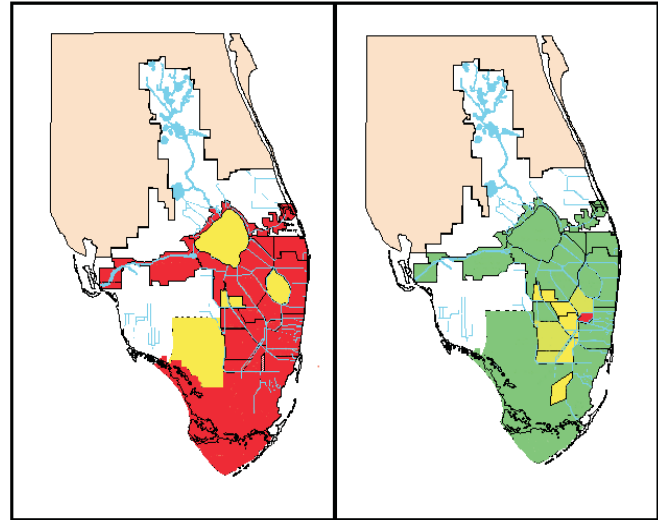
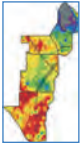


Figure 13. The anticipated effect of the original Comprehensive Everglades Restoration Plan (CERP). Without the Plan (left) restoration targets are not expected to be met (red). With the Plan fully implemented (right) restoration targets are more likely to be met (green). Yellow indicates uncertainty in meeting restoration targets (USACE and SFWMD 1999).

Protection and Restoration

During the 1970s and 1980s there was growing recognition of threats to the Everglades. Many of the problems with declining ecosystem health revolve around water: water quantity, quality, timing, and distribution (Figure 12). Consequently, a 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 federal Water Resources Development Acts of 1992 and 1996 directed the U.S. Army Corps of Engineers (USACE) 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.evergladesrestoration.gov/>), 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 and the South Florida Water Management District (SFWMD) and over 100 ecologists, hydrologists, planners, engineers and other professionals from over 30 federal, state, tribal, local agencies and the public. The Plan includes: about 180,000 acres of surface water storage areas; about 36,000 acres of man-made wetlands to treat urban or agricultural runoff from basins other than the EAA; wastewater reuse; extensive aquifer storage and recovery; water management operational changes; and structural changes to improve how and when water is delivered to



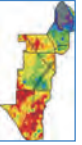
Evaluating restoration success requires reliable pre-restoration and post-restoration information on ecosystem condition.

the Everglades, including removal of some of the canals or levees that prevent natural overland sheet flow. 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 with economic consequences, and the ability to protect people and their property from flooding will be compromised (USACE and SFWMD 1999). CERP includes over 50 projects. The initial focus is on regaining some of the water storage capacity that was lost with wetland drainage by building water storage reservoirs, restoring water quality with treatment wetlands, restoring surface water sheet flow, and enhancing water management options. The entire Plan will take many decades to implement and cost over \$23 billion as of 2020 (USACE and USDOJ 2020; \$16 billion as of 2014 and \$8 billion as of 1999, Congressional Research Service 2017). The cost is generally split equally by the taxpayers of Florida and the United States. A key to Everglades restoration is the Central Everglades Planning Project (CEPP) which includes: increasing storage, treatment and conveyance of water south of Lake Okeechobee; removing canals and levees within the central Everglades; and retaining water within Everglades National Park and protecting urban and agricultural areas to the east from flooding (USACE 2014).

Example CERP Everglades Ecosystem Restoration Performance Measures

(RECOVER 2007)

Water Management	Reinstate system-wide natural hydropatterns and sheet flow
Habitat Alteration	Increase spatial extent of habitat and wildlife corridors
Eutrophication	Water total phosphorus is not to exceed 10 micrograms per liter and should not exceed OFW concentration levels. Decrease the areal extent of areas with soil phosphorus exceeding 500 milligrams per kilogram (mg/kg) and maintain or reduce to 400 mg/kg or less. Surface water total nitrogen should be \leq 1994-2004 baseline.
Mercury Contamination	No statistically significant increase in levels of mercury in fish tissue, state water quality standards will be met
Sulfate Contamination	Maintain or reduce surface water sulfate to 1 milligram per liter or less
Surface Water Specific Conductance	No more than 25% increase above background, maintain low specific conductance in the Refuge
Periphyton	Increase aerial coverage of habitats that reflect Natural Systems Model
Soil Loss	Restore natural soil formation processes and rates



EVERGLADES REGIONAL ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM (REMAP)

Given the multi-billion dollar taxpayer investment in CERP and efforts to control phosphorus and mercury, monitoring and assessment are important. Monitoring data are needed to determine ecosystem conditions, identify threats, detect changes, and evaluate environmental restoration efforts in a holistic manner. Monitoring objectives include:

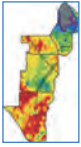
- Documenting status and trends;
- Determining baseline variability;
- Detecting responses to management actions;
- Improving the understanding of cause and effect relationships.

Accordingly, CERP has adopted an integrated monitoring and assessment plan that includes key performance measures as indicators of ecosystem health. Performance measures are tools to allow the public and managers to predict system-wide performance of alternative plans and to assess actual performance following implementation. Achieving targets for performance measures is expected to result in system-wide sustainable restoration (RECOVER 2007). Everglades REMAP data have been used by CERP for performance measures, the monitoring and assessment plan, the system status report, and the 5-year Report to Congress (USACE and USDOJ 2015).

Program Design

The attention and funding devoted to Everglades ecosystem protection and restoration are unprecedented. It is important to regularly and comprehensively assess ecosystem health in a cost-effective, quantitative manner. Such an assessment identifies resource conditions and restoration needs, and allows one to determine the effectiveness of restoration and pollution control efforts. A defining feature of the Everglades is its large spatial area. Therefore, to document conditions and track restoration it is important to accurately determine the proportion of the current Everglades that is subject to various impacts or stressors.

The Everglades Regional Environmental Monitoring and Assessment Program (REMAP) permits a holistic view of indicators of ecological condition throughout the freshwater Everglades landscape. An indicator is a measurable characteristic of the environment, abiotic or biotic, that can provide information on the condition of ecological resources. REMAP's large-scale perspective is critical to understanding the impacts of different factors (such as phosphorus, mercury, sulfur, habitat alteration, or hydropattern modification) on the entire Everglades landscape, rather than at individual locations or in small areas. Looking only at isolated sites in a specific area and extrapolating to the larger ecosystem can be misleading.

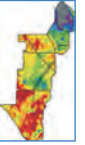


Probability Samples

REMAP employs a statistical, probability-based sampling strategy, similar to polls or surveys. This approach was initiated throughout the United States in the early 1990s by USEPA (USEPA 1993, Thornton et al. 1994, Diaz-Ramos et al. 1996, Stevens 1997). 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 Academies of Sciences, and USEPA has applied it to lakes, rivers, streams, wetlands, estuaries, forests, arid ecosystems and agro-ecosystems throughout the United States (Olsen et al. 1999, USEPA 1993, 1995).

In a probability sample, or survey, every member of the population has a known chance of being selected as the samples are drawn at random. The probability design USEPA uses to sample the Everglades was developed from the Environmental Monitoring and Assessment Program (EMAP) base grid, a generalized random-tessellation stratified approach (Stevens and Olsen 2004). The design includes locating stations separately within each of the four major Everglades subareas in order to assure a sufficient number of stations in the smaller subareas (the Refuge and WCA2, as compared to WCA3 or the Park). Every location within each subarea had an equal chance of being sampled. Estimates for the entire study area are made possible by accounting for unequal sample size among subareas. Estimates also can be made for individual subareas. The sampling design is not biased to favor one marsh type over another (e.g., selecting a specific location because it looks good or bad, sampling next to a road or airboat trail because it is easier, or avoiding tall, dense sawgrass or cattail (Figures 15 and 16) because it is difficult to sample). Probabilistic designs have two strengths: a) the results represent the spatial distributions of the environmental parameters that were measured; and, b) the results can be used to estimate, with known confidence, the proportion of the study area that was in any given condition, and how much the proportion changed. For example, the proportion of the Everglades marsh having a surface water sulfate concentration greater than 1.0 milligram per liter (mg/L, the CERP goal) was 37.1 ± 5.0 % during the 2014 sampling, and this proportion was statistically significantly smaller than the 57.3 ± 6.0 % measured during the 2005 sampling (Wald F test). This change indicates an improved condition in 2014. During 2014, 118 stations were sampled in the 2098 square-mile study area, and each station represents an average of about 18 square miles of marsh area. REMAP design disadvantages at this sampling density include the assumption of minimal heterogeneity throughout the 18-square mile area, and stations may not fall in localized areas with gradients near and downstream of water control structures, such as the phosphorus gradient in WCA2A. A transect sampling design along gradients, or a greater density of stations, are preferable in these areas.

In the Phase IV 2014 sampling, USEPA utilized a design approximating a 50-50 mix of new random points and points from the previous phase (phase III, 2005). USEPA's Office of Research and Development, Western Ecology Division, National Health and Environmental Effects Research Laboratory, provided the statistical design and sample draw. The 2014 statistical design is a probability survey design that consists of two parts: a) 50% of the sites are a probability subsample of the prior survey design (a resample of 58 stations sampled in 2005); and b) 50% of the sites (60 stations) are a new probability sample. Since the



REMAP data provide a snap-shot of conditions throughout the Everglades during a two-week sampling window. REMAP detects change among survey events. Statements or inferences should not be made about conditions between surveys, especially for quickly-changing media such as surface water.

two designs are completed independently, the combined survey design is also a probability survey design. The combined design has two objectives: estimate the current status of the Everglades across space; and detect change, or lack thereof, from prior time periods (2014 versus 1995 or 2005). An advantage of this combined approach is that the power of detecting a change is increased by visiting some sites in both time periods (Breidt and Fuller 1999, USEPA 2015).

Throughout REMAP Program planning, a focus has been to assure that data meet key information needs of managers and scientists involved with Everglades protection and restoration. REMAP Program leaders met with Florida and Federal managers and scientists involved with CERP and Everglades phosphorus and mercury control efforts, including Everglades National Park, Arthur R. Marshall Loxahatchee National Wildlife Refuge, the Army Corps, the SFWMD and the Florida Department of Environmental Protection (FDEP). REMAP study plans have been subjected to external scientific peer review by these agencies and by the USEPA REMAP national program office. Efforts have been coordinated across agencies to avoid redundancy and maximize the information gained. Funding for REMAP phases has been provided by the Park, the Refuge, the Army Corps, FDEP, and USEPA.

Elements such as carbon, nitrogen, phosphorus, oxygen, hydrogen and sulfur are critical components of living organisms. These elements cycle through ecosystems, plants, animals, air, water, and soil. These cycles are called biogeochemical cycles, because they include a variety of biological, geological, and chemical processes. A major focus of REMAP is sampling for these elements, and these data are referred to as biogeochemical data. The biogeochemical data are the focus of this report.

REMAP provides a snapshot of conditions across the Everglades landscape during a two-week sampling window. Conclusions about conditions are based on the freshwater Everglades study area as a whole. REMAP detects change, or lack of change, by comparing survey events. Because the frequency of sampling is low (marsh sampling 5 years out of 20), statements about change should not be construed as traditional trend analysis. This is especially true for surface water constituents such as sulfate, specific conductance and nutrients, which can change quickly due to local rain events and water management operations. The concentrations observed during a two-week REMAP sampling snapshot may not represent conditions observed during other weeks in the same wet season. Consequently, statements or inferences should not be made about conditions during time periods that were not sampled. Long-term monitoring networks at fixed stations sampled more frequently, such as annually (the USGS Greater Everglades Priority Ecosystems Program) or weekly or monthly (the SFWMD's data that are reported by the SFWMD and FDEP in the annual South Florida Environmental Report), are better suited for making statements about surface water conditions at a location throughout the year, and identifying trends across consecutive years.

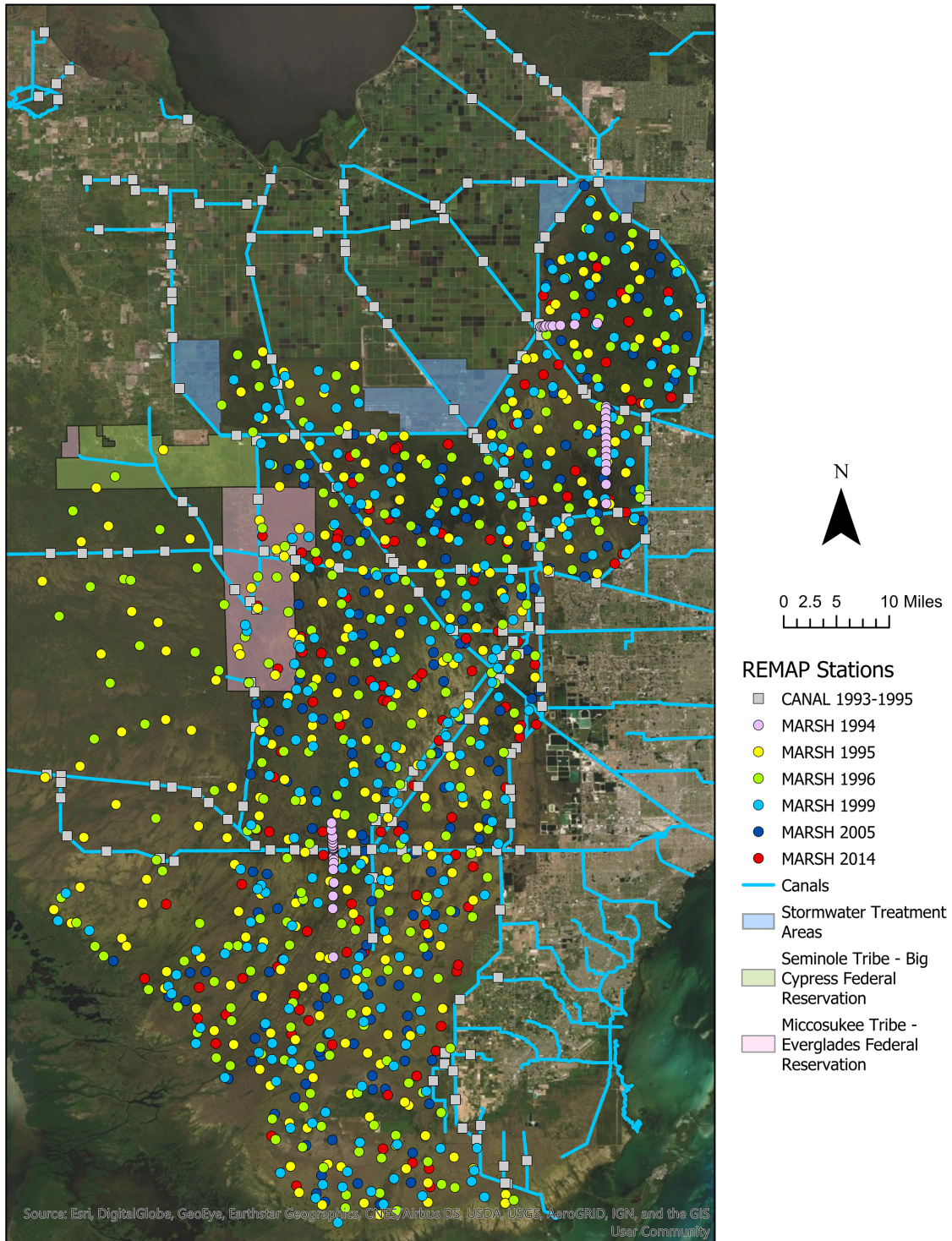
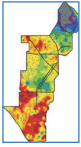
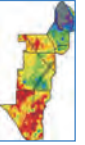


Figure 14. All 1250 stations sampled by REMAP from 1993 to 2014. Canals - 199 randomly located stations (4 sampling events 1993-1995), and marsh - 45 transects stations (1994) and 1006 randomly located stations (10 sampling events across 4 phases 1995-2014). See Table 1.

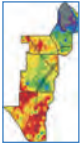


Everglades REMAP History

Everglades REMAP began sampling in the freshwater portion of the Everglades in 1993. REMAP was the first effort in the Everglades to sample canals at randomly located probability-based locations away from water control structures. Canals were sampled during the wet season in September 1993 and 1994, and during the dry season in May 1994 and 1995 (about 50 sites per sampling cycle) (Table 1, Figure 14, Stober et al. 1995, 1998; Scheidt et al. 2000). Four marsh transects (45 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 (Stober et al. 1998). The eastern portion of Big Cypress Swamp within Big Cypress National Preserve, the Seminole Tribe of Indians' Big Cypress Federal Reservation, and the Miccosukee Tribe of Indians of Florida's Federal Reservation in the Everglades were 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 (Stober et al. 2001a, 2001b). Phase III was conducted in May 2005 and November 2005 at another 228 Everglades marsh sites (Scheidt and Kalla 2007). Phase IV was conducted



Figure 15. Biogeochemical sampling included surface water (top left), floc and soil (bottom left), and mosquitofish (top right). The surface water sampling apparatus (top left) and soil coring device (bottom left) were designed and constructed for Everglades REMAP. Crews sample in all habitats, including dense sawgrass and cattail mix (bottom right).



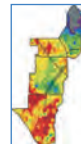
Phase	I	II	III	IV
Year(s)	1993 - 1996	1999	2005	2013 - 2014
Distinguishing features	Baseline data. Multiple stressors. Big Cypress & canals included.	Change detection. Added periphyton assessment & plant studies. Omitted Big Cypress & canals.	Change detection. Added food web studies & invasive plant survey.	Change detection. Wet season only. Omitted aquatic community ecology & some macrophytic plant studies.
Canal Stations	199	0	0	0
Marsh Stations	240 dry season 240 wet season 480 total	119 dry season 119 wet season 238 total	109 dry season 119 wet season 228 total	51 wet season 2013 118 wet season 2014 169 total
Biogeochemical Media				
Surface water	X	X	X	X
Floc		X	X	X
Porewater		X	X	
Bottom water				X
Soil	X	X	X	X
Periphyton	X	X	X	X
Mosquitofish	X	X	X	X
Macrophytic Vegetation		X		X
Macrophytic Plants				
Qualitative habitat categorization	X	X	X	X
Species frequency		X	X	
Classified vegetation mapping		X	X	X
Invasive plant survey			X	
Aquatic Community Ecology				
Periphyton assemblage		X	X	
Mosquitofish food habits		X		
Macroinvertebrate assemblage			X	
Isotope studies			X	

Table 1. Everglades REMAP history showing phases, media and indicators.

during September 2013 at 51 marsh sites (USEPA 2014a; Richards et al. 2017) and September of 2014 at 118 marsh sites (Kalla and Scheidt 2017). As of 2014, REMAP has sampled 1051 different marsh locations and 199 canal locations throughout the freshwater Everglades or Big Cypress, representing the ecological condition in 3,000 square miles of freshwater marsh and over 750 miles of canals.

Phase IV Sampling

In late September 2013, the USEPA Region 4 Science and Ecosystem Support Division (SESD) initiated a Phase IV wet season sampling event at 125 stations, and collected biogeochemical data at 51 stations



within ENP and WCA3 (USEPA 2014a, Richards et al. 2017). Due to a federal government shutdown during the sampling period, this event was not completed. Sampling for the entire study area was reinitiated and completed in September 2014, and those results are presented here. The September 2014 Phase IV sampling included two efforts:

- WorldView-2 satellite imagery of a 1 km² area centered on 65 REMAP sampling stations was used to produce classified vegetation community maps. Vegetation mapping provides a landscape context for REMAP biogeochemical and biotic information. Standing stocks of carbon, nitrogen and phosphorus in sawgrass, water, soil, floc, and periphyton were also estimated (Richards et al. 2017);
- multi-media biogeochemical sampling was conducted to understand water quality and soil conditions. This report focuses on the biogeochemical sampling.

The biogeochemical effort included seven media (Table 1, Appendix I) that were sampled concurrently and consistently throughout the freshwater Everglades marsh. USEPA field crews sampled 118 stations during a 16-day period in September 2014 (Figure 15). Not all media were present at each station: surface water (n=116 stations); bottom water (the water at the bottom of the water column, immediately above the soil-water interface) (116); marsh soil or sediment (0 to 10 cm profile) (117); floc (flocculent detrital material found at the surface water-soil interface (96)); prey fish (mosquitofish) (104); composite periphyton (visible and floating within the water column plus epiphytic or 'sweaters' attached to plants) (71); benthic periphyton (discrete layer at the soil surface) (42). In addition, sawgrass, the most common plant in the Everglades, was sampled at a subset of stations: sawgrass leaf clippings (the middle 20 centimeters of a representative leaf from three sawgrass plants) (60); and whole sawgrass plants (27). These media are important for elucidating the cycling of nutrients and mercury. Unlike some long-term sampling programs, REMAP does not have a minimum surface water sampling depth due to the importance of shallow conditions in understanding cycling processes for mercury and nutrients.

Digital photographs were taken to document conditions at each sampling location- ground view of the area sampled to the left of the helicopter, nine panoramic photos at 45-degree increments, each of the three soil cores, and an aerial view at 100 to 200 feet. For each station, photodocumentation, classified vegetation maps, and biogeochemical data are available at: <http://digir.fiu.edu/gmaps/EverREMAP.php>.

Data Quality Assurance

Everglades REMAP has defined data quality objectives to ensure that data are of known and documented quality that satisfy predefined uses and requirements. An independently reviewed Quality Assurance Program Plan (QAPP) was developed in accordance with USEPA protocol (USEPA 2002, 2014b). Data quality is an essential component of the work, throughout planning, field sampling and laboratory analyses, and final data review and validation. USEPA Region 4 SESD Field Branch Standard Operating Procedures were followed as applicable (<https://www.epa.gov/quality/quality-system-and-technical-procedures-lsasd-field-branches>).

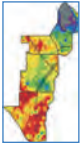


Figure 16. The probability-based sampling design ensures that all habitats, such as dense cattail, are sampled.



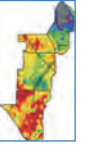
Figure 17. Surface water and pore water samples in the chain of custody lab during 2005 at the end of a day's sampling. During 2014 samples were distributed to four analytical laboratories for determination of nutrient, ion and mercury content.

During 2014 SESD was accredited for both field and laboratory operations by the American National Standards Institute - American Society for Quality National Accreditation Board. Some field sampling equipment and procedures have been developed specifically for Everglades REMAP (USEPA 2014a).

During the September 2014 sampling, USEPA field personnel collected about 2140 samples (Figure 17). Four analytical laboratories performed the analyses for these samples. 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. Laboratory analytical methods and minimum detection limits are identified in the Project QAPP (USEPA 2014a). There were about 60 laboratory test methods performed on the samples, including forms of phosphorus, nitrogen, sulfur, carbon, mercury and physical parameters (Appendix I). Approximately 4,930 laboratory analytical sample results were produced, 100% of which were subjected to an independent quality assurance review. All analytical results met data quality objectives and none of the results were rejected. About 10% of the budget was invested in data quality assurance. Including field measurements, approximately 7,000 data values were generated. All biogeochemical and physical data are available at: <https://www.epa.gov/everglades/environmental-monitoring-everglades>.

Data Uses

REMAP data have been used for many purposes by environmental decision makers and scientists from over 30 Florida or federal agencies, Indian Tribes, non-governmental organizations, and agricultural and environmental interests. Program data have been used in over 40 peer-reviewed scientific journal



The REMAP Program consistently documents conditions throughout the Everglades in a quantitative manner. This documentation helps to assess the effectiveness of Everglades protection and restoration activities.

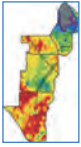
publications or agency reports (see Program reports after Literature Cited section). REMAP Program reports or publications with REMAP data have been cited thousands of times. Key users include those that have provided funding, support, or sampling access: Everglades National Park, Arthur R. Marshall Loxahatchee National Wildlife Refuge, the Miccosukee Tribe of Indians of Florida, the Seminole Tribe of Indians, the U. S. Army Corps of Engineers, Florida Department of Environmental Protection and USEPA. The National Academies of Sciences also have relied on REMAP data in their scientific reviews of CERP and Everglades restoration progress (National Research Council (NRC) 2008, 2010, 2012, 2014).

REMAP data can be used to help answer questions about multiple issues:

- Water management (e.g., water depth)
- Water quality and eutrophication (e.g., phosphorus concentrations in water, soil, vegetation and periphyton; cattail distribution)
- Habitat alteration (e.g., wet prairie and sawgrass marsh distribution, presence of exotic plant species)
- Mercury contamination (water, soil, algae, and prey fish)

Specific Everglades restoration questions that REMAP helps to answer include:

- 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 has a soil total phosphorus concentration greater than 500 milligrams per kilogram (mg/kg), Florida's definition of phosphorus-impacted for Everglades soils, or 400 mg/kg, the CERP restoration target?
- 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 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? Has this loss rate changed over time?
- How much of the marsh has prey fish with mercury levels that exceed 77 micrograms per kilogram, a level that presents an increased risk to top predators such as wading birds?
- What water quality conditions are associated with high mercury in fish?



Everglades REMAP Data Uses

1- Support **Everglades restoration efforts** (used by many Florida and federal agencies, and in scientific publications): South Florida Water Management District (SFWMD); U. S. Army Corps of Engineers (USACE) 1996, 2014; USACE and U. S. Department of Interior (USDOI) 2015; RECOVER 2007, 2011; National Academies of Sciences (NRC) 2008, 2010, 2012, 2014; Wetzal et al. 2017.

2- Assess **water management practices** and drought-related ecological risk in the Everglades (SFWMD, Smith et al. 2003).

3- Document **soil thickness and subsidence** in the Everglades and identify areas that need to be restored with more water (USACE, SFWMD, National Park Service - Everglades National Park, Scheidt et al. 2000, Scheidt and Kalla 2007; NRC 2010, 2012, 2014; USACE 2014; Dreschel et al. 2018).

4- Model **water quality implications of Everglades water restoration alternatives** (Naja et al. 2017).

5- Determine which portions of the Everglades are **phosphorus-impacted** according to Florida's Everglades phosphorus criterion rule and assessing the effectiveness of Florida's multi-billion dollar phosphorus control effort (Florida Department of Environmental Protection (FDEP), SFWMD, United States Fish and Wildlife Service (USFWS) - Arthur R. Marshall Loxahatchee National Wildlife Refuge, Everglades National Park, USEPA; (Payne et al. 2001, 2002)

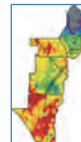
6- Determine **landscape patterns of soil nutrients and contaminants** (USACE, USEPA, SFWMD, Everglades National Park, Loxahatchee National Wildlife Refuge; Osborne et al. 2011a; NRC 2008, 2012).

7- Understand morphological **response of plant species to phosphorus** (Richards and Ivey 2004).

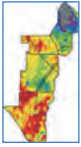
8- Determine the **effects of phosphorus on periphyton, invertebrates and fish** (Sargeant et al. 2010, 2011).

9- Understand spatial variations in **aquatic food webs and food web structure** and drivers (Abbey-Lee et al. 2013).

10- Map **vegetation** and determine vegetation classes, associations, biomass, nutrient standing stocks, and presence of exotic plants (Richards et al. 2008, 2017; Zweig and Newman, 2015).



- 11- Understand **sulfur cycling, the sources and distribution of surface water sulfate**, the penetration of water with high sulfate content into the Everglades marsh, and whether there should be water quality standards for sulfate (FDEP, SFWMD, USEPA; SFWMD 2007, Axelrad et al. 2007, 2008; NRC 2010, 2012; Corrales et al. 2011, Gabriel et al. 2014a, Orem et al. 2011, Julian et al. 2016b, Orem et al. 2019).
- 12- Understand the **penetration of water with high ionic content** from agricultural areas into the low ionic content marsh in the Refuge and its potential impacts on natural periphyton communities (USFWS - Loxahatchee National Wildlife Refuge; McCormick and Harvey 2007; NRC, 2010, 2012; McCormick et al. 2011).
- 13- Document **water quality** background conditions and develop **performance measures for soil phosphorus and surface water conductivity and sulfate** for the multi-billion dollar Florida-Federal Comprehensive Everglades Restoration Plan (USACE, SFWMD, Everglades National Park, Loxahatchee National Wildlife Refuge; RECOVER 2007).
- 14- Determine **landscape patterns of periphyton**, and the role of periphyton mats in aquatic consumer community structure (USACE, SFWMD, Everglades National Park; Loxahatchee National Wildlife Refuge; Gaiser et al. 2011; Trexler et al. 2014).
- 15- Document **mercury conditions, landscape patterns, and mass balance** in soil, water, plants and biota (Liu et al. 2008a, 2008b, 2015; Richards et al. 2017).
- 16- Document **mercury biomagnification** from water or sediment to fish and understand the ecological risk to Everglades birds (FDEP, SFWMD, USEPA, USACE, Loxahatchee National Wildlife Refuge, Everglades National Park; PTI 1995; USACE 1996; USEPA 1997; Axelrad et al. 2007; Julian 2013a, 2013b).
- 17- Elucidate the **environmental conditions, such as sulfur, carbon and phosphorus, that may influence mercury in prey fish** (FDEP, SFWMD, USACE, USEPA, Loxahatchee National Wildlife Refuge, Everglades National Park; Liu et al. 2009, 2011; Julian et al. 2013a, 2013b, 2016b, 2017a; Dierberg et al. 2014; Pollman 2012, 2014, 2019; Pollman and Axelrad 2014; Jiang et al. 2018, Rumbold 2019a; Kalla et al. 2019)
- 18- Evaluate the distribution, potential sources and controlling factors of **toxic metals** (Li et al. 2015).
- 19- Determine **carbon and organic matter** characteristics and drivers across the Everglades landscape (Yamashita et al. 2010).
- REMAP data have been presented by Program personnel in over 40 peer-reviewed scientific journal publications or agency reports.



Data Analysis and Presentation

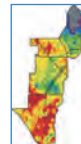
Kriging

A strength of Everglades REMAP is its spatial coverage. Kriging is a geostatistical method of generating contour maps to understand and display data across space (Figure 21). The contours are isopleths, lines of equal estimated value for the 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. Sampling stations are shown on krigs with black dots. 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. An underlying assumption of variograms is that values from points closer together are more similar than those from points farther apart. Fifty-eight of the stations sampled in 2014 were also sampled in 2005. For the soil parameter krigs, data from both years were used. Krigs are included in this report to provide visual information across space. Conclusions about the spatial extent of conditions, or that conditions were different during sampling events, are made not from the krigs, but rather from rigorous statistics (the cumulative distribution function and the Wald F-test, see below).

In the Everglades, there are physical barriers to water sheet flow, such as levees and roads. However, during the peak of the wet season (generally the time of wet-season REMAP samplings reported here), the subareas of the Everglades are hydrologically connected by surface water flowing through numerous water control structures. The 2014 sampling took place from September 4-20. During this time, and the month before, all of the Stormwater Treatment Areas were discharging into the Everglades, and there was water moving across the subareas: from the Refuge to WCA2A, WCA2A to WCA3A, and from WCA3A to the Park at Shark River Slough (Abteu and Ciuca 2016). The same was true of the November 2005 sampling, except that there was no flow from the Refuge into WCA2A. While wet season connectivity is not complete, isolation of the subareas is not complete either. Reality lies somewhere in between, and is dependent upon location, ground relief, water management operations, and proximity to canals, levees and water control structures. Some water quality constituents, such as surface water total mercury, are driven more by atmospheric deposition than by water flow, minimizing the influence of physical barriers such as levees. For these parameters, kriging was performed on the entire study area as one unit. Other constituents, such as surface water chloride, conductivity, sulfate and pH, are influenced by surface water inflows and proximity to canals and levees, especially in the vicinity of the Refuge and WCA2. For these constituents krigs were done by subarea.

Spearman rank order correlations

Correlation is a statistical tool for determining the strength of association between two variables. Parametric statistical tests assume that the data values are random, and independent. In the Everglades, values for some constituents, such as sulfate in surface water, occur mostly near the low end of their range, while some large values also occur. These data are not normally distributed, but instead are skewed. In addition, the



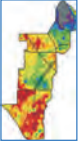
sulfate concentration at one location tends to be similar to the concentrations observed at nearby locations, so these values are not independent (see Figures 40-41). Nonparametric statistics, such as the Spearman rank order correlation, are preferable for such data.

If two variables are perfectly correlated, the change in one variable is accompanied by equivalent change in the other variable. The correlation coefficient can be any number between -1 and +1. Positive values indicate direct correlation, where one variable increases as the other increases, whereas negative values indicate inverse correlation (one variable decreases as the other variable increases). Coefficients near 0 indicate lack of correlation. REMAP measurements vary over space (station to station). Data from the same sampling event can be analyzed for correlation because the measurements at a station were obtained at the same time. For the 2014 sampling, correlation coefficients and their statistical significance have been reported (Kalla and Scheidt 2017). The significance (p) of a statistic is a measure of the reliability of the sample data set as 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. A correlation coefficient of $p < 0.001$ indicates a 1 in 1000 chance that the two variables are not associated. For example, the correlation coefficient between surface water sulfate and conductivity was 0.71, which was significant with a probability < 0.001 (Kalla and Scheidt 2017). Correlation or association between two variables does not necessarily indicate that there is an underlying explanation or cause. Results are highlighted here only if $p < 0.001$ and if there is a plausible mechanism or process to explain why the two variables would be correlated.

CDFs and area estimates

One way to visually portray survey statistics is to plot the cumulative distribution function (CDF) of the data. A CDF curve can be used to estimate the area (proportion) of the Everglades where a given analyte was found at a concentration above or below any value of interest. This is a key strength of REMAP's probability-based sample design. The estimates of area by CDF curve in this report were generated from the original data, using algorithms and scripts for the R statistical package developed by EMAP statisticians at the USEPA Office of Research and Development. Krigs were not used to estimate CDF curves. In this report, the CDF curve is shown in bold. By reading up to the CDF curve from any concentration of interest on the x-axis, and then across from the curve horizontally to the y-axis, one can read the corresponding proportion of the Everglades 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 percent values 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 Everglades study area was outside the range defined by the confidence interval.

For example, looking at the CDF for mosquitofish mercury in 2014 (Figure 71), in 2014 $87 \pm 6\%$ of the 2,098-square-mile Everglades study area had mercury concentrations in mosquitofish below $77 \mu\text{g}/\text{kg}$, a threshold to protect birds and mammals that feed on fish (USEPA 1997). The 95% CI around the 87% estimate



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

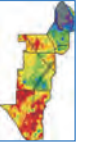
is $\pm 6\%$, which is within the $\pm 10\%$ REMAP data quality objective tolerance limits for 95% CIs. Previous experience in the national EMAP Program and in the earlier phases of Everglades REMAP (Scheidt and Kalla 2007) indicated that approximately 125 stations was a sufficient sample size to meet this objective.

Statistical testing for differences across sampling year (F test)

Any pair of REMAP data sets for a given variable, represented by their respective CDF curves, can be tested statistically to indicate a difference, or lack thereof, between them. The Wald F test was used to test 2014, 2005, and 1995 CDF curves against each other to determine whether there was a significant change in conditions among sampling events. This test allows for statistical inference to the sampled population, or study area. If curves from different time periods differ, the underlying condition of the resource can be said to have changed, although nothing can be inferred about the intervening years. Statements about change are made with a specified degree of confidence, typically no more than a 1 in 20 chance of being wrong (probability < 0.05). The source of such an error is that the supposed difference is due merely to samples that inaccurately represented the population, instead of being a real change in the resource. The random REMAP sample spread out over the entire Everglades study area can be used to draw conclusions about changed conditions across the whole area. In this report, the largest p-value from the F test used to support a conclusion that there was a changed condition is 0.03. In addition, a weight of evidence approach was used. While comparing krigs may suggest changed conditions, this assertion was corroborated by not only an F test with $p < 0.05$ (Wasserstein et al. 2019), but also by lack of overlap of the CDF curve 95% confidence intervals across years, lack of overlap of the boxes in the box and whisker plots, and a plausible explanation for a change in condition.

Box and whisker plots

A box and whisker plot (for example, Figures 31 or 36) is a graphical method of displaying the variation, or general shape, of a data set. The large box contains the middle 50% (the interquartile range between the 25th and 75th percentiles) of the data values. The median is shown by the square symbol or horizontal line within the box. Half of the values are greater than the median, or 50th percentile, and half are less. The whiskers or vertical lines include values outside the interquartile range that are not considered outliers or extremes. Outliers are defined as values that are smaller than the 25th percentile or larger than the 75th percentile, respectively, by at least 1.5 times the interquartile range. Extremes are values that are smaller than the 25th percentile or larger than the 75th percentile, respectively, by at least 2 times the interquartile range.



WATER CONDITIONS

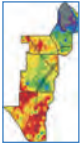


Figure 18. Rainfall at an Everglades wet prairie-slough in WCA3 during 2005. Surface water depth is about 2 feet.

Water is the lifeblood of the Everglades. The historic Everglades was defined by: highly seasonal rainfall; shallow, 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 (durations of surface water inundation). Slowly-flowing water helped create the ridge and slough landscape that is a defining feature of the Everglades. Water depth and hydroperiod affect fish populations, as well as wading bird feeding habitat, prey availability, and nesting success. During the 1900s, anthropogenic changes in surface water depth, distribution and hydroperiod caused many harmful impacts to the Everglades. Water is key to ecosystem preservation and restoration.

South Florida water management operations are complex and involve balancing the water supply and flood control needs of urban areas, agriculture, and the environment. Canals can move Lake Okeechobee water east to the St. Lucie Estuary, west to the Caloosahatchee Estuary, or south through the Everglades Agricultural Area (EAA) into the Everglades. These southern canals then pass through the Everglades marsh on their way to outlets along the east coast (Figures 10 and 14). Water in these canals can also flow through water control structures into the Everglades marsh. In the EAA, the canals are used for irrigation, drainage and flood control, depending on the season and local rainfall. In drier years, less water flows from Lake Okeechobee and the EAA downstream into the Everglades.

Each of the Everglades WCAs and Lake Okeechobee have regulation schedules that are used by the Army Corps and SFWMD to manage water levels and releases. The regulation schedules have water level thresholds that vary with time of year, and trigger water releases that are made to protect the integrity of



Everglades Region Annual Rainfall (inches)			
Average WY 1991-2020	WY 1996	WY 2006	WY 2015
51.6	60.8	48.1	47.7
3 Month Inflow water volume (1000 acre-feet)			
	September 1995	November 2005	September 2014
LNWR	432.6	90.9	124.1
WCA2	542.6	265.2	422.4
WCA3	1,068.3	487.3	628.9
Park	659.4	802.4	498.1

Table 2. Annual rainfall for REMAP sampling years and period of record, and three-month discharge into the Refuge, WCA2, WCA3 and the Park.

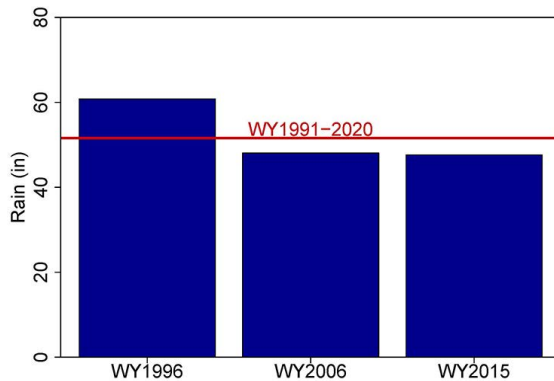


Figure 19. Everglades region annual rainfall (inches) for water years 1996, 2006 and 2015 as compared to the WY1991 - WY 2020 annual average.

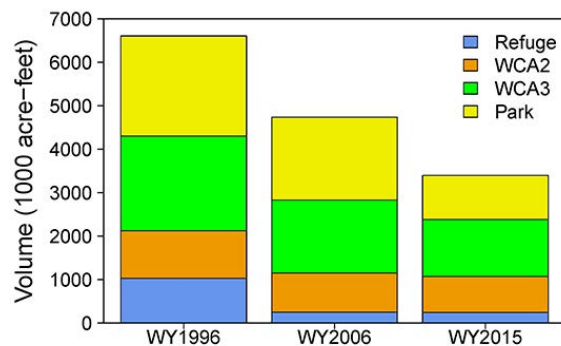


Figure 20. Annual flow (thousand acre-feet) into the Refuge, WCA2, WCA3 and the Park during water years 1996, 2006 and 2015.

levees and developed areas, and to lower water levels in preparation for wet season rainfall and inflows. The regulation schedules are developed through public processes, and are designed to balance competing objectives including water supply, flood control, and environmental enhancement.

Rainfall in the Everglades is highly seasonal, with about 80% falling during the May to October wet season (Figure 18). Climatic events such as tropical storms, droughts and El Niño all have a profound effect on rainfall. In South Florida, a water year (e.g., WY15 is May 1, 2014 to April 30, 2015) is used to summarize rainfall and hydrologic data. For the years with wet season REMAP sampling events, annual rainfall throughout the Everglades was comparable in WY06 (48.1 inches, 93% of WY91-WY20 annual average) and WY15 (47.7 inches, 92%), and highest in WY96 (60.8 inches, 118%) (Figure 19, Table 2).

Water flow into and within the Everglades is highly seasonal and varies annually and by location. During the month of REMAP sampling and the prior two months, flows at all structures into the Refuge, WCA2 and WCA3 were highest in 1995, lowest in 2005 and intermediate in 2014. In contrast, for the Park inflow was highest in 2005 (Table 2, Abtew et al. 2007, Abtew and Ciuca 2016). Annual inflows into the Refuge, WCA2, WCA3, and the Park were highest in WY96, lower in WY06 and lowest in WY15 (Figure 20). Inflow does not dictate marsh water depth since outflow may balance inflow.

The Stormwater Treatment Areas (STAs) discharged 1.32 million acre-feet of treated water into the Everglades WCAs from the north in WY15 (Pietro et al. 2016), as compared to 1.48 million acre-feet in WY06 (Pietro et al. 2007). During the September 2014 sampling and the month before, all of the STAs were discharging, and there was water moving from the Refuge to WCA2A,

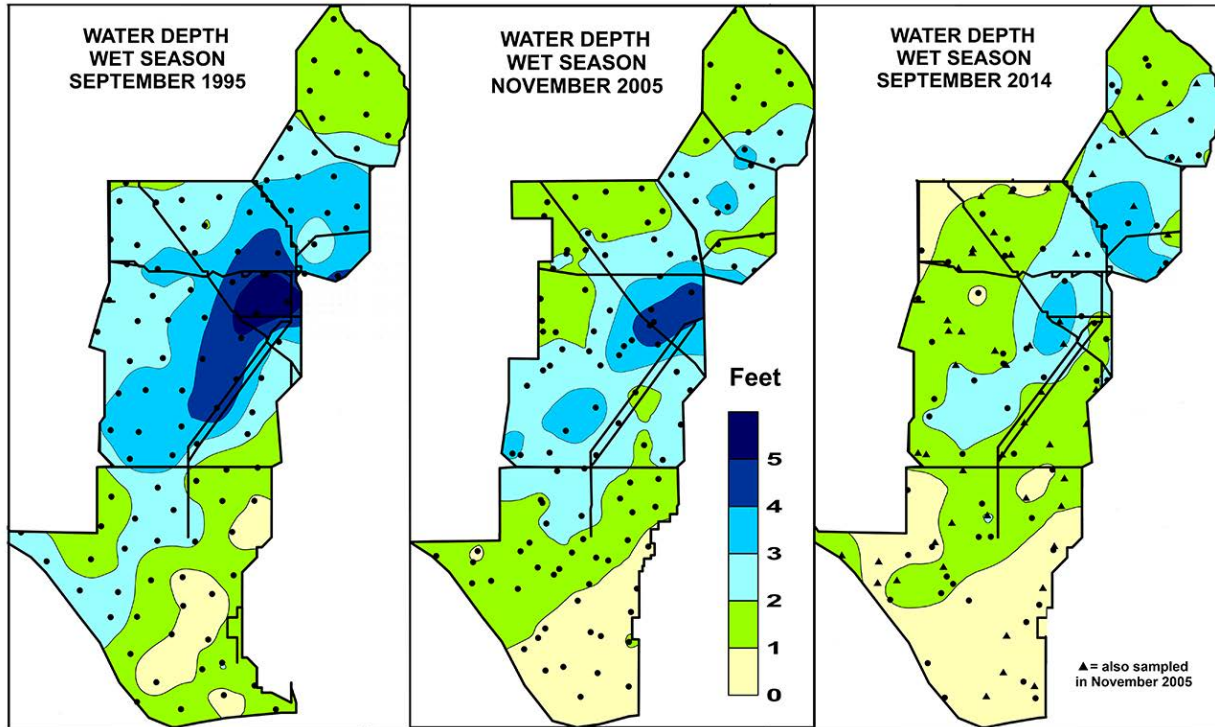
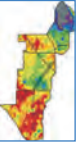


Figure 21. Krigs of measured surface water depth encountered in the Everglades marsh during the 1995, 2005 and 2014 REMAP wet season sampling events.

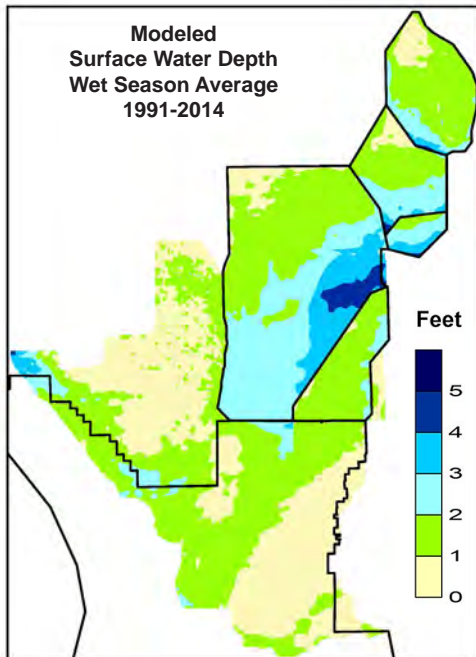


Figure 22. Wet season average surface water depth, September to November, 1991-2014. From Everglades Depth Estimation Network (EDEN), courtesy of USGS.

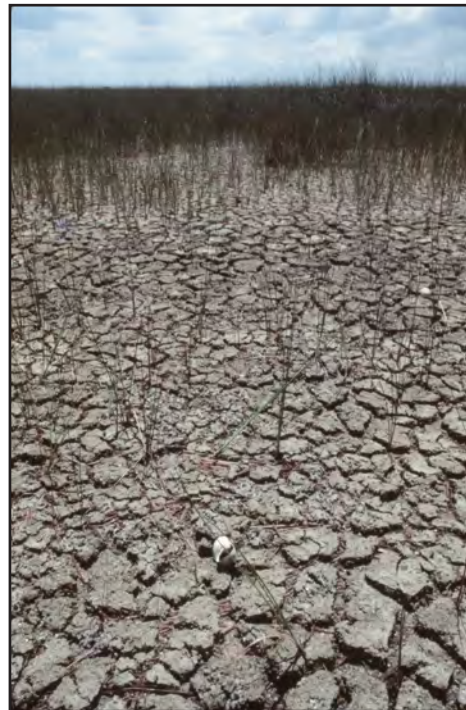
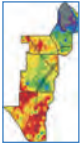


Figure 23. Dry marsh in Everglades National Park. The Eastern Marl Marsh within the Park is dry on average about 40% of the year.



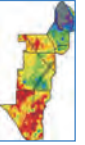
WCA2A to WCA3A, and from WCA3A to the Park at Shark River Slough (Abtew and Ciuca 2016). The same water movement was true for the November 2005 sampling, except that there was no flow from the Refuge to WCA2A (Abtew et al. 2007).

Marsh water depths vary greatly with season, year and location in response to short-term and long-term rainfall and flow from water control structures (Figures 18, 21-23). During all REMAP 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 southern portions of the Refuge, WCA2 and WCA3A (Figures 21-22). Unnaturally deep water (over five feet) was observed in 1995 within eastern WCA3A where the L67 levee prevents water sheet flow to the south. Short hydroperiod portions of the marsh dry out in most years, such as the marl marshes within the Park (Eastern Marl Marsh and Ochopee Marl, see soil section) and northern WCA3A (yellow areas in Figure 21). Figure 22 shows Everglades Depth Estimation Network (EDEN; Haider et al. 2020) model projections by USGS of average wet season water depth for September to November, 1991-2014. The overall result of rainfall and water management operations was that for most of the Everglades water depths during the 1995 sampling were deeper than a typical wet season. This was the year with the highest rainfall, and the highest water flow into the WCAs. For the Park and WCA3A the shallowest conditions were observed in 2014, the year with the lowest flow into the Park at Shark River Slough, which may in part reflect new Everglades Restoration Transition Plan water management operations that were initiated in 2012.

WATER QUALITY

Nutrients

Nutrients are elements that are essential for plant growth. Phosphorus (P), nitrogen (N), and potassium are considered the primary nutrients, and they are the most common nutrients in fertilizer. The Everglades marsh is phosphorus-limited (McCormick et al. 1999; McCormick et al. 2002), which means that very low concentrations of P naturally limit undesirable biological growth. The consequence of P limitation is that elevated P concentrations cause undesirable ecological responses, such as changes in algal and plant communities, and loss of dissolved oxygen in water. Much of the attention about Everglades water quality has been focused on controlling P in order to stop its deleterious ecological effects. Although N enrichment has not been identified as a concern in the freshwater Everglades, it is a concern in coastal waterbodies including Florida Bay and the Caloosahatchee and St. Lucie Estuaries. Florida has adopted protective numeric nutrient criteria (total phosphorus, total nitrogen and chlorophyll a, Chapter 62-302.532(d) and (z) F. A. C.) for the St. Lucie and Caloosahatchee Estuaries, and has identified the loads of pollutants such as nutrients that are required to meet water quality standards in Lake Okeechobee, and the St. Lucie and Caloosahatchee Estuaries.

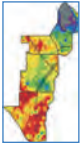


Phosphorus

The natural Everglades marsh has very low total phosphorus (TP) concentrations of less than 10 µg/L (micrograms per liter, or parts per billion (ppb)) in surface water (McCormick et al. 1999, Noe et al. 2001). Concentrations can be as low as the laboratory analytical method detection limit of 2 ppb (Julian et al. 2016d). Historically, rainfall was the dominant source of external phosphorus, and the hydrology of the marsh was rainfall-driven, with slow, overland, shallow sheet flow supplying water to downstream wetlands. There were no canals in the Everglades prior to the early 1900s. This naturally nutrient-poor condition resulted in a unique mosaic of wetland habitats, such as sawgrass marshes, wet prairies and sloughs, and algal communities (periphyton) that developed under low TP conditions. Well-developed periphyton communities are a defining characteristic of the Everglades, and they play a critical role in food webs, habitat, soil formation and water quality (McCormick 2011).

The first canals that dissected the Everglades were completed by 1917. From 1954-59 levees forming the boundary of the EAA were constructed, along with pump stations to provide flood control. From 1960-63 levees were completed that compartmentalized the Everglades into WCAs, along with structures allowing flow into and out of the WCAs (Light and Dineen 1994). The canal system became an inadvertent conduit for transport of high levels of nutrients in water pumped out of the EAA into the Everglades. Water quality became a concern (Cornwell et al. 1970, Marshall 1971, Storch 1971, US Department of Interior 1971), and by the 1970s scientists began to observe phosphorus impacts in Everglades marshes, especially in the Refuge and WCA2A (Dineen 1973, Gleason 1975a, 1975b, SFWMD 1977). From 1979-88 the flow-weighted TP concentrations discharged into the Refuge from the north and west were 198 ppb and 144 ppb at pump stations S5A and S6 respectively, and they were 129 ppb at the S10 structures that discharge from the Refuge into WCA2A, as compared to marsh interior concentrations of about 10 ppb or less (SFWMD 1992a). At this time there were no numeric phosphorus requirements for water within or flowing into the Everglades. In the Everglades, annual or long-term means for phosphorus at water control structures are typically expressed as a flow-weighted mean. When calculating a flow-weighted mean, the TP concentration data are weighted by the flow during the time period that the concentration represents in order to provide an accurate estimate of average conditions.

During the 1980s, TP impacts in the Everglades became well-documented (Swift 1981, Dineen 1986, Frydenborg and Ross 1987, Swift and Nicholas 1987, LOTAC II 1988, Belanger et al. 1989, Scheidt et al. 1989, SFWMD 1992a, Davis 1994). Phosphorus impacts are most evident downstream of canal and water structure inflows to the Refuge, WCA2A, the Miccosukee Tribe of Indians' Everglades Federal Reservation in WCA3A, and the Park (Doren et al. 1996, Childers et al. 2003, Wright et al. 2009, Osborne et al. 2013). Among the undesirable, cascading eutrophic impacts to the Everglades are altered periphyton communities, loss of water column dissolved oxygen, increased soil phosphorus content, conversion of the wet prairie-sawgrass mosaic to tall, dense single-species stands of cattail with minimal open water, and subsequent loss



of wading bird foraging habitat. Vegetation impacts can be observed from satellite imagery. These collective changes impact the structure and function of the aquatic ecosystem (McCormick et al. 1999, Payne et al. 2001, McCormick et al. 2002, Gaiser et al. 2005, McCormick et al. 2009). By about 1990, over 40,000 acres of the Everglades were impacted by cattail expansion (Davis 1994). How clean the water should be, how to control phosphorus, and who should pay for these efforts became the subject of federal litigation in 1988 (Godfrey and Catton 2006, Rizzardi 2001a, 2001b). This resulted in the first requirements for TP control programs (Consent Decree (CD), U. S. District Court 1992), which became incorporated into Florida's 1994 Everglades Forever Act (EFA).

Today, all of the Everglades has a numeric water quality criterion of 10 ppb for phosphorus. In 1999 the Miccosukee Tribe of Indians of Florida adopted, and under the Clean Water Act USEPA approved, a 10 ppb TP criterion for the Everglades portion of the Tribe's Federal Reservation in WCA3A (Figure 14). In 2005 Florida adopted and USEPA approved a 10 ppb water quality criterion for TP in the Everglades Protection Area (EPA), which includes the Refuge, Park and WCAs (FAC 62-302.540). The objective of both of these water quality criteria is to prevent nutrient-induced imbalances in natural populations of aquatic flora or fauna. Florida's TP criterion is applied in the EPA as a long-term average, with achievement of the criterion within the Everglades waterbody determined by data collected monthly at a network of fixed long-term marsh sampling locations. In the Everglades, geometric means are routinely used to average marsh phosphorus data to minimize the influence of extreme high values on the average. Compliance is determined by a 4-part test specifying that:

- 1) the five-year geometric mean averaged across all stations is ≤ 10 ppb;
 - 2) the annual geometric mean averaged across all stations is ≤ 10 ppb for three of five years;
 - 3) the annual geometric mean averaged across all stations is ≤ 11 ppb; and
 - 4) the annual geometric mean at each individual station is ≤ 15 ppb.
- Each of the four parts must be met to achieve the criterion (FAC 62-302.540(4)). The test is intended to simultaneously: allow for the natural temporal and spatial variability that is observed at marsh reference sites; be sensitive enough to detect long-term increases in TP above 10 ppb; and place an upper limit on phosphorus at individual marsh locations. The same test is applied separately 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, achievement of the criterion is determined not by the 4-part test at marsh stations within the Park, but rather by P

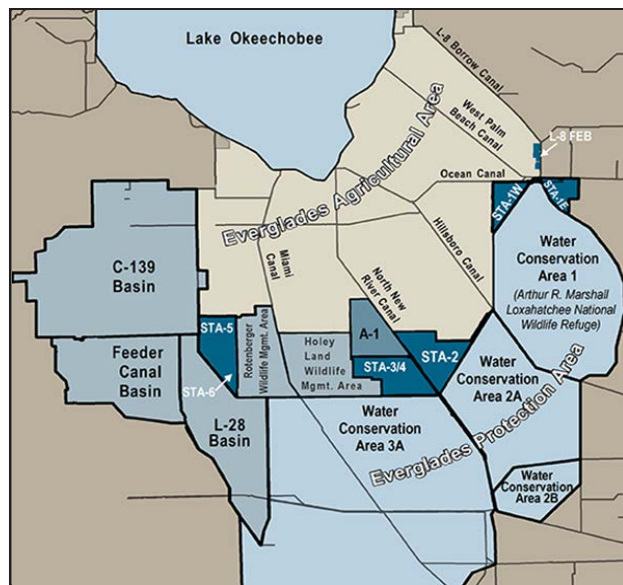
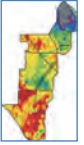


Figure 24. Location of phosphorus control program treatment wetlands (Stormwater Treatment Areas, or STAs) operational in 2017. In combination with agricultural best management practices, they are to discharge phosphorus into the Everglades at a long-term concentration equivalent to the 10 part per billion water quality standard. A-1 is a shallow Flow Equalization Basin that equalizes water flow into the STAs (adapted from SFWMD).



concentration requirements at Park inflow structures ('at the door')(U. S. District Court 1992, SFWMD 1992b). Because REMAP data are not collected monthly throughout the year at fixed sampling locations, it is not possible or appropriate to apply Florida's 4-part test for assessing the 10 ppb criterion to REMAP marsh data. However, because of REMAP's probability-based design, it is appropriate to make statements about the area of the marsh that exceeds a concentration of interest, such as 10 ppb, during individual REMAP sampling events, although these statements have no regulatory bearing.

The Park and Refuge have an additional level of water quality protection because they have been designated by Florida as Outstanding Florida Waters (OFWs). This antidegradation designation requires that the quality of water that existed the year prior to March 1, 1979 must be maintained. To protect these OFWs, the CD requires a long-term average geometric mean TP concentration of 7 ppb at a network of 14 interior marsh stations in the Refuge, and a long-term flow-weighted mean (FWM) of 8 ppb at inflows to the Park at Shark River Slough, and 6 ppb at inflows to the Park at Taylor Slough, respectively (SFWMD 1992b, U. S. District Court 1992, Walker 2000). These Park requirements were also adopted in the Florida Administrative Code. In addition, CERP has a performance measure for surface water TP: 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 (RECOVER 2007).

Phosphorus control programs, required by the CD and Florida's EFA, were initiated in the 1990s in order to prevent further loss of Everglades plant communities and wildlife habitat. The initial phase of this program required that TP in discharges from the EAA into the Everglades be at 50 ppb or less. Control was achieved by a combination of agricultural Best Management Practices (BMPs) and about 47,000 initial acres of constructed treatment wetlands within the EAA (the Everglades Construction Project, ECP) referred to as Stormwater Treatment Areas (STAs) (Figure 24). Agricultural BMPs were required to be in place by 1995. The first prototype STA (the Everglades Nutrient Removal Project, 3700 acres) began treating water in 1994 (Chimney and Goforth, 2006). The REMAP Phase I sampling period (1993-96) 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 at the EAA basin level.

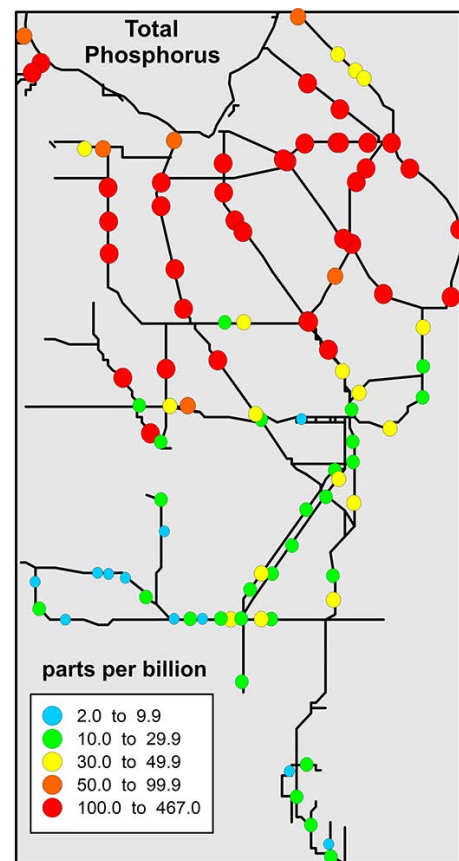
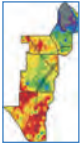


Figure 25. Total phosphorus ($\mu\text{g/L}$) in surface water at 99 random locations in canals sampled by REMAP during the wet season, September 1993 and 1994 (Scheidt et al. 2000). At this time there were no phosphorus controls. Phosphorus conditions have improved since the 1990s due to the STA and EAA agricultural BMP programs.



During the 1990s, REMAP documented that canal TP concentrations had 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). During the 1993-94 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 (Figure 25, Scheidt et al. 2000). These data represent conditions before TP controls were initiated.

TP concentrations in surface water during September 2014 are shown in Figure 26. About 70% of the Everglades marsh stations sampled by SFWMD had TP ≤ 10 ppb, and 35% had TP ≤ 5 ppb. The highest marsh TP of 42 ppb was in WCA2A near canal inflows. For the 28 days prior to REMAP sampling, STA inflows were 61-142 ppb FWM (provisional data) and discharges were 13-21 ppb, except for STA5/6 which had an inflow of 240 ppb and a discharge of 28 ppb (SFWMD 2014). For WY15, annual geometric mean TP concentrations at marsh stations within the Park, away from canals and anthropogenic nutrient sources, were as low as the laboratory analytical method detection limit of 2 ppb (Julian et al. 2016d). In contrast, TP concentrations in water flowing into the Miccosukee Tribe of Indians of Florida's Federal Reservation in WCA3A were 76 and 78 ppb, greater than the Tribe's 10 ppb water quality criterion (Figure 26).

SFWMD's extensive long-term data, as frequent as bi-weekly at fixed locations, show improving TP conditions in the Everglades (Julian et al. 2016a). SFWMD average annual TP data at the inflows to the

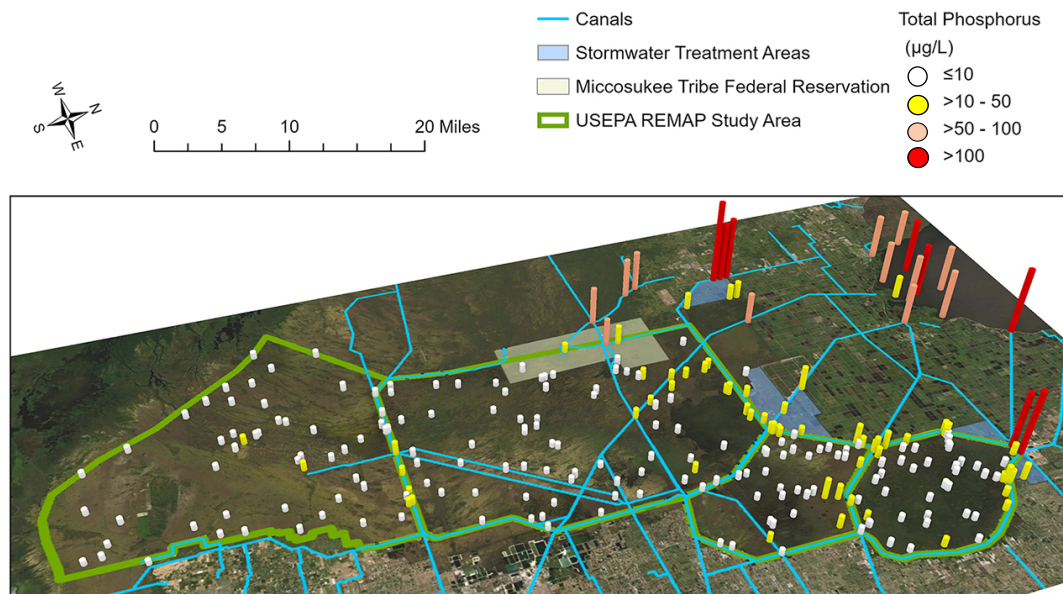
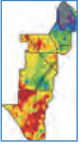


Figure 26. Total phosphorus ($\mu\text{g/L}$) in surface water during September 2014 at 116 REMAP Everglades marsh stations. Also shown are SFWMD data for 12 locations in Lake Okeechobee and about 100 locations in the Everglades marsh (geometric mean), and 33 water control structures in canals (geometric mean when flowing) including selected STA inflows and outflows.



four subareas ranged from 12-21 ppb for WY15 (2014), as compared to 10-67 ppb during WY06 (2005, Table 3). Interior marsh annual geometric mean TP concentrations also improved from 6-18 ppb in 2005 to 4-9 ppb in 2014. REMAP data also show progressively lower surface water phosphorus concentrations from 1995 to 2005 to 2014 (depicted in Figure 27 and evaluated in Figure 28). For September

	INFLOW		OUTFLOW		INTERIOR	
	Flow-weighted mean				Geometric mean	
	2005	2014	2005	2014	2005	2014
EAA BMP Basins			117-221	62-144		
STAs	144 (104-213)	99 (72-230)	44 (21-146)	17 (15-32)		
Refuge	67	20			15	9
WCA 2	27	15			18	9
WCA 3	24	21			10	5
Park	10	12			6	4

Table 3. Annual surface water total phosphorus concentration (ppb) from selected Everglades locations for WY06 (2005) and WY15 (2014) (data from SFWMD).

2014, 14.8 ± 4.8% of the marsh had a TP concentration higher than 10 ppb, an improvement from the 27.2 ± 7.5% observed during November 2005 (Figure 28). Conditions were worse during September 1995 when 57.8 ± 7.8% of the Everglades marsh had TP greater than 10 ppb. The proportion of the marsh above 10 ppb was cut in half twice for these three years, and the improvements indicated by the CDF curves are significant (Wald F, p=0.04).

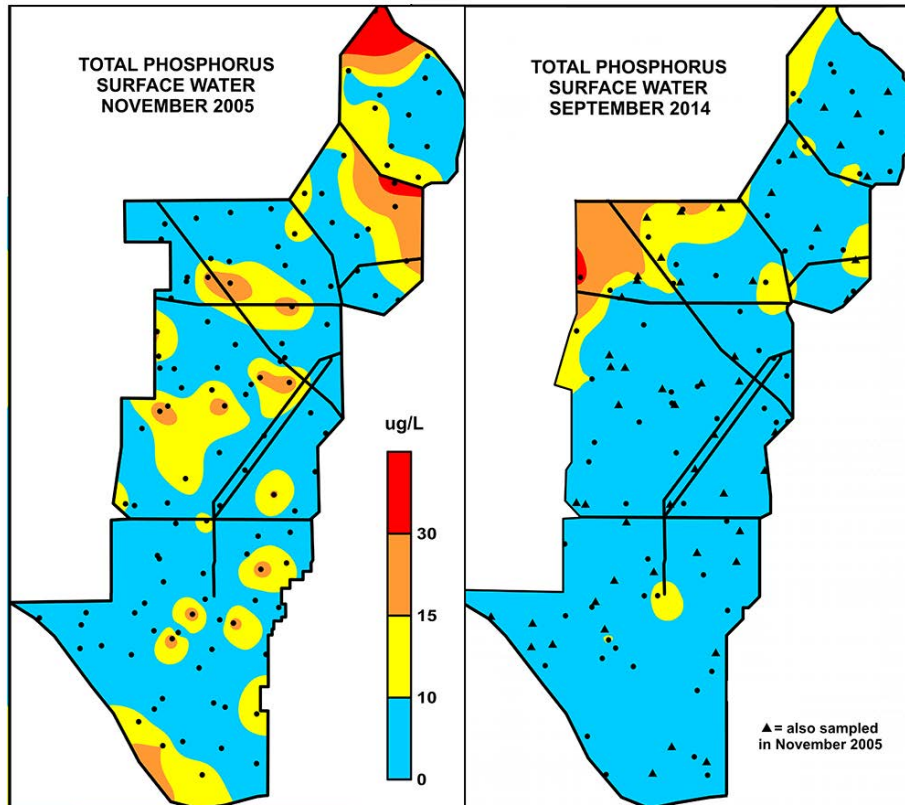


Figure 27. REMAP total phosphorus concentration in surface water (µg/L) during November 2005 (left) and September 2014 (right).

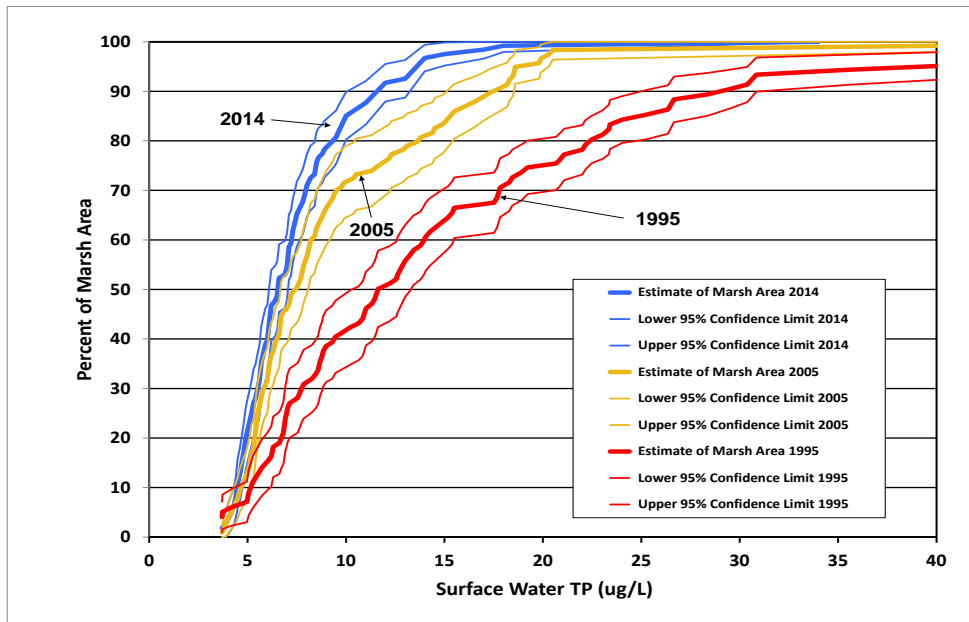
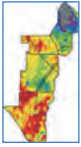
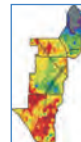


Figure 28. Surface water total phosphorus concentration estimates of marsh area for 1995, 2005 and 2014 wet season REMAP samples. The areas greater than 10 ppb were progressively smaller, reflecting improved conditions (Wald F test).

The improvement in Everglades water phosphorus concentrations since 1995 is due to the EAA BMP program (Izuno et al. 1999, Daroub et al. 2009, 2011, Lang et al. 2010, Yoder et al. 2020) and Florida's STA program. From 1996 to 2015, it is estimated that the BMP program removed 3001 metric tons of TP (a 56% TP load reduction) from the EAA basin as compared to the load that would have been expected without BMPs. Post-BMP EAA TP concentrations for WY15 were 93 ppb basin-wide, with a 79% load reduction (SFWMD 2016a, Iudicello et al. 2016). In addition, the area of STAs treating post-BMP water increased by 73% from 32,980 acres during the REMAP 2005 sampling to 57,045 acres during the 2014 sampling. This is the largest wetland treatment system in the world. For WY15, flow-weighted annual mean TP inflow to the STAs ranged from 72 ppb for STA2 to 230 ppb for STA5/6, with an average inflow for all STAs of 99 ppb. STA discharge concentrations into the Everglades ranged from 15 ppb for STA3/4 to 32 ppb for STA5/6, with an average discharge across all STAs of 17 ppb, as compared to 44 ppb for WY06 and the previous REMAP sampling (Table 3). The overall WY15 load reduction for the STAs was 83%. The cumulative amount of phosphorus retained by the STAs from 1994 to 2015 was about 2000 metric tons, which is 75% of the inflow load (Pietro et al. 2016). This is about two-thirds of the amount removed by agricultural BMPs. It is easier to remove P near the source where concentrations tend to be higher. In WY06, the flow-weighted TP concentration discharged into the Refuge, WCA2 and WCA3 was 64 ppb (Payne et al. 2007). In WY15 it improved to 19 ppb (Xue 2016). Some of the cells or flowways within the better performing STAs, STA2 and STA3/4, have discharged at 13 ppb for several years. Complex factors affect STA TP removal and outflow TP, including calcium (Juston and DeBusk 2011), annual hydraulic and phosphorus loading rates, hydraulic residence time, inflow TP concentration, water depth, vegetation coverage and condition, soil characteristics, antecedent land use, and extreme weather (Chen et al. 2015, Zhao and Piccone 2020). While there is considerable



Water phosphorus concentrations were much lower in 2014 than in 2005 and 1995-96 due to agricultural BMPs and the Stormwater Treatment Areas

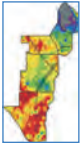
effort underway to reduce future phosphorus loads into the Everglades, areas of the Everglades that are impacted by P often are dominated by cattails, which are resilient (Bansal et al. 2019). Active management in these P-impacted areas may speed their recovery (Hagerthey et al. 2014).

During 2012, USEPA and Florida reached consensus on additional Everglades water quality Restoration Strategies (SFWMD 2012). STA discharge permits and consent orders issued by FDEP require: a) TP at the discharge from each STA shall not exceed 13 ppb as an annual flow-weighted mean (equivalent to 10 ppb as a geometric mean at the STA discharge) in more than 3 out of 5 water years on a rolling basis, and shall not exceed 19 ppb as an annual flow-weighted mean in any water year; b) expansions to STA1W totaling 6,500 acres; c) about 110,000 acre-feet of water storage areas (flow equalization basins) that will slowly release water to the STAs in order to improve their performance; d) an enforceable compliance schedule for \$880 million of projects with completion dates of 2018 to 2025; and e) a monitoring and research plan to confirm that the performance of each STA is optimized and restoration is moving forward. The Regional Administrator for USEPA Region 4 and the Secretary of the FDEP meet bi-annually to ensure that progress is being made until each STA meets the 13 ppb long-term phosphorus discharge limit. Technical representatives from state and federal agencies also meet at least twice annually to review research, evaluate operation of the STAs, and assess water quality and progress in achieving the deadlines.

Florida has also developed a comprehensive long-term plan for achieving water quality goals for the other basins (non-ECP) that discharge into the Everglades (Burns and McDonnell 2003). This plan to treat large volumes of stormwater down to 10 ppb TP is unprecedented. The plan recognizes that additional control measures are necessary to ensure that discharges to the Everglades from all basins meet water quality standards (Iudicello et al. 2016), including the basins flowing into western WCA3A.

Soil Phosphorus

Excess phosphorus in marsh soils is an aggregate indicator of TP enrichment over a longer time scale than TP in the water column. In portions of the Everglades with peat soils there is an association between increasing soil TP and cattail encroachment. Various elevated soil TP concentrations have been used as indicators of enrichment or where cattails occur: 700 milligrams TP per kilogram of soil (mg/kg) (Childers et al. 2003); 610 mg/kg (Walker and Kadlec 1996); and 600 mg/kg (Craft and Richardson 1993, Payne et al. 2001). Florida's Everglades TP criterion rule defines P-impacted areas as being where soil TP exceeds 500 mg/kg (FAC 62-302.540(3)(d)). 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 (RECOVER 2007).



REMAP data (average of three cores, 0-10 centimeter soil depth) show spatial gradients in soil phosphorus (Figures 29 and 30). These results are similar to landscape data obtained by others for the Everglades in 2003 (Corstanje et al. 2006, Sklar et al. 2006, Bruland et al. 2007, Osborne et al. 2011a) and in 2005 (Osborne et al. 2015). REMAP data indicate no change in TP concentration in soil system-wide in 2014 as compared to 2005 (Wald F, $p=0.82$; Figure 31). There also was no change for the Park, Refuge, WCA2 and WCA3 subareas. This is in contrast to the 2005 sampling, when REMAP documented higher soil TP in 2005 than in 1995-96 (Wald F, $p < 0.05$) (Scheidt and Kalla 2007). Other efforts also documented increases in Everglades soil TP from 1990-2003. Spatial expansion of elevated soil TP within WCA2A occurred from 1990-98, such that the WCA2A median changed from 516 mg/kg to 860 mg/kg (Grunwald et al. 2004). Soil TP data within WCA3A collected from 1992 and 2003 indicated that the area with soil TP > 500 mg/kg increased from 21% to 30% (Bruland et al. 2007). Transect sampling downstream of inflow structures along TP gradients in the Refuge and WCA2A in 1989 and 1999 also indicated expansion of the area with soil TP > 700 mg/kg (Childers et al. 2003).

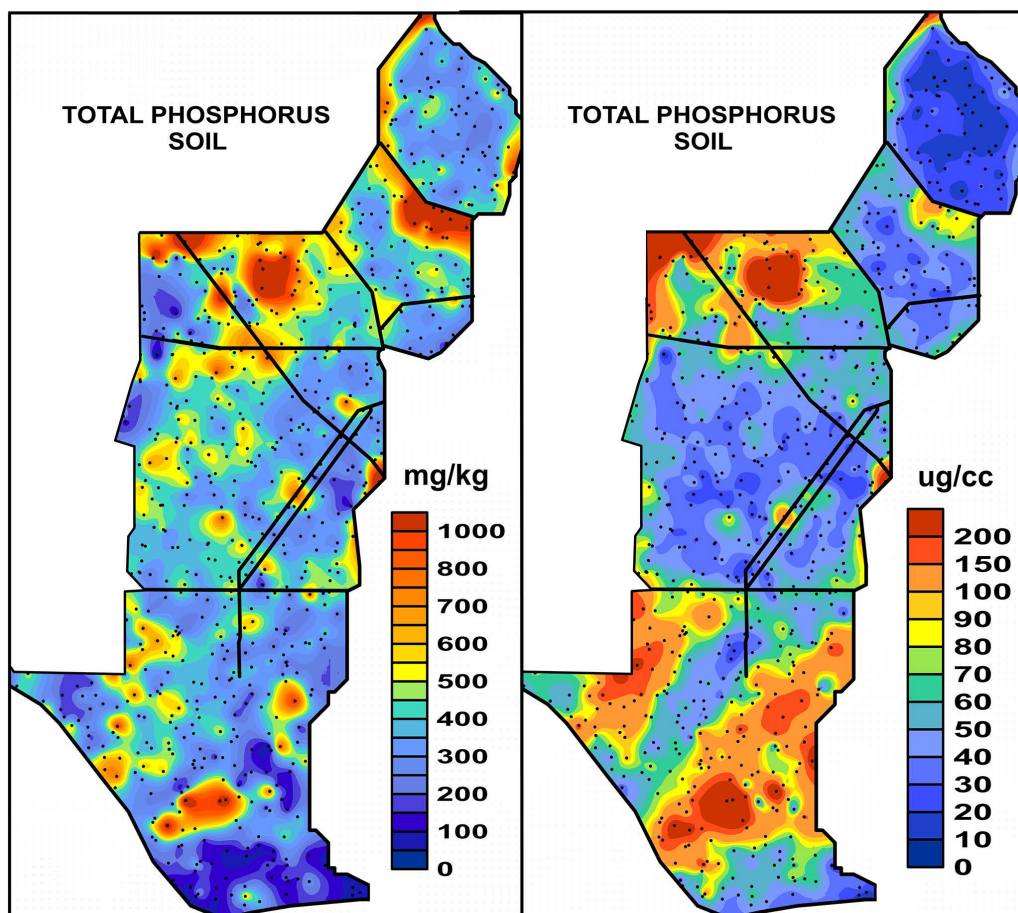


Figure 29. REMAP data from 1995, 1996, 2005, and 2014 for total phosphorus in soil expressed as milligrams phosphorus per kilogram of soil (left) and as micrograms of phosphorus per cubic centimeter of soil (right).

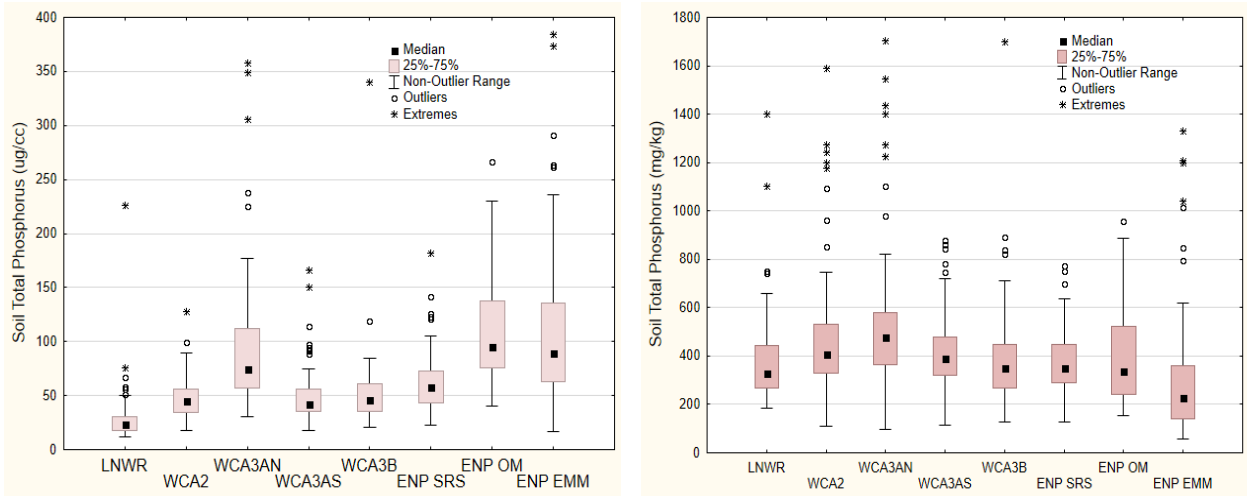
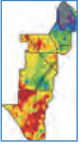


Figure 30. REMAP data by subarea for total phosphorus in soil expressed as micrograms of phosphorus per cubic centimeter of soil (left) and milligrams phosphorus per kilogram of soil (right). Data are from 1995, 1996, 2005, and 2014.

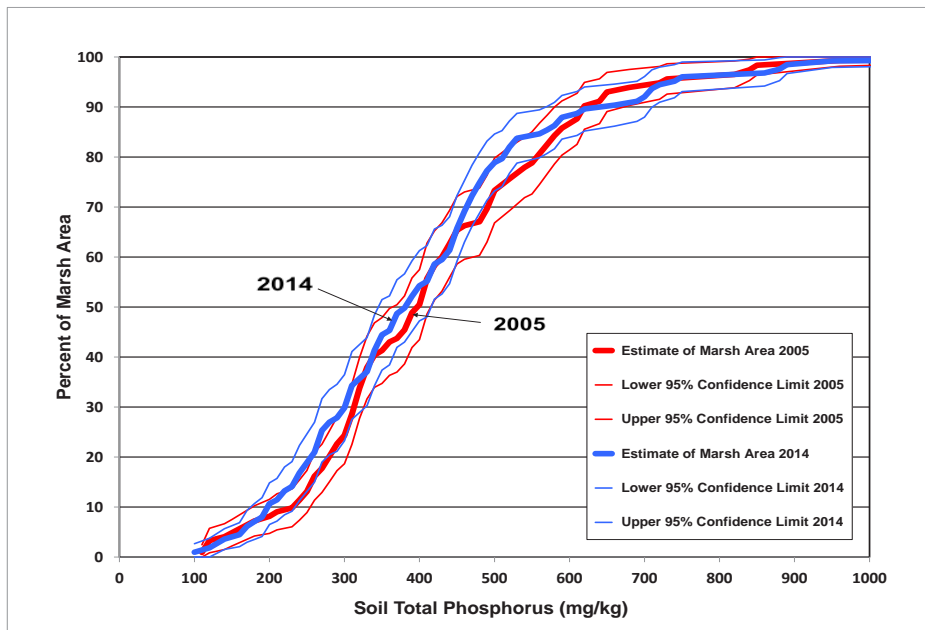
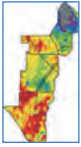


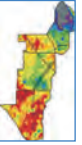
Figure 31. Soil total phosphorus (mg/kg) estimates of marsh area for 2005 and 2014 wet season REMAP samples. The percent of marsh area greater than 500 mg/kg did not change significantly from 2005 to 2014 (Wald F test).

Landscape-wide, the median REMAP soil TP concentration was 390 mg/kg in both 2005 and 2014, as compared to 343 mg/kg in the 1995-96 wet season, and 325 mg/kg in the 1995 wet season. For 2014, the area of the Everglades with soil TP concentrations exceeding the 500 mg/kg impacted threshold was $21.1 \pm 5.6\%$, which is not statistically different than the $24.5 \pm 6.4\%$ observed in November 2005 (Wald F test, Figure 31). This contrasts with $16.3 \pm 4.1\%$ exceeding 500 mg/kg in 1995-96. In 2014, $45.3 \pm 7.1\%$ of the marsh



exceeded the 400 mg/kg CERP restoration goal, as compared to $49.3 \pm 7.1\%$ in 2005 and $33.7 \pm 5.4\%$ in 1995-96 (Scheidt and Kalla 2007). Small-scale heterogeneity exists, particularly in Park soils. During 2014 each sampling station represented 17.8 square miles of marsh. Because of the sampling density and the random design, gaps in the sampling stations can result in no information for key areas of interest with high soil phosphorus, such as in portions of WCA2A near inflow structures (Figures 27 and 29). Documenting change at locations with the highest vulnerability to enrichment, such as near inflow structures, and documenting restoration success in these areas, necessitates a spatially-focused intensive monitoring design (Cohen et al. 2009a, Osborne et al. 2011b). These designs include transects along phosphorus gradients, or an increased density of sampling stations.

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 marl soils (median of 0.36 g/cc for Park marl soils, Figures 55-56). Soil phosphorus can be expressed on a mass basis as milligrams of phosphorus per kilogram of soil, or on a volume basis as micrograms of phosphorus per cubic centimeter of soil. When soil TP is adjusted for bulk density (Figure 29 right), TP is more uniform throughout the areas with peat soils, and the locations in WCA3A south of I-75 that were above 500 mg/kg ("impacted") no longer have high TP. Peat soils with higher TP are generally limited to WCA2A and the edges of the Refuge. The places with the lowest bulk density have the lowest soil phosphorus. 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 $\mu\text{g/L}$ (McCormick et al. 1999; Julian et al. 2016a, 2016d). Higher soil TP concentrations at some locations may reflect peat versus marl soil types, and may be influenced by soil loss due to oxidation and subsidence and higher bulk density. Soil TP concentrations in the 300-600 mg/kg range may not be an appropriate indicator of enrichment for mineral (marl) soils within the Everglades (USEPA 2000).



Nitrogen

Nitrogen (N) is the most abundant nutrient in the Everglades and it plays an important role in nutrient cycling. In phosphorus-impacted areas, N can become the nutrient that limits undesirable biological growth (Inglett et al. 2011). Although the concentrations of N that are discharged from the EAA and the STAs are higher than those found in the downstream marsh, overall, N enrichment has not been identified as a concern in the Everglades. Most of the nitrogen flowing into the Everglades is in the organic form, which is not as reactive as inorganic forms such as nitrite, nitrate and ammonia. Nitrogen cycles within water bodies in organic and inorganic forms. Nitrification is the oxidation of ammonium to nitrate, the form of N that is most easily assimilated by many plant species. Denitrification is the reduction of nitrate to N gas, which can leave the water body and enter the atmosphere. Although denitrification is a potential pathway for N loss from Everglades surface waters, this pathway is not major. Ten percent of nitrogen was lost from peat soils to denitrification, while 34% was lost from marl soils (Gordon et al. 1986), and the rate of removal increased as soils became more phosphorus-enriched (Gordon et al. 1986; White and Reddy 2003).

The water quality criterion for 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 (FAC 62-302.530(48)(b)). CERP adopted an Everglades restoration goal for N of less than or equal to the baseline mean observed during 1994-2004; however, the N concentrations for this baseline have not been defined (RECOVER 2007). Most coastal marine systems are N-limited, and therefore N is important as the nutrient that limits undesirable biological growth in the marine portions of the Everglades, such as Florida Bay. It is important to holistically understand restoration efforts and the potential effects that increased freshwater flows may have on nitrogen processes (Inglett et al. 2011).

Surface water total nitrogen (TN) during the September 2014 sampling had a spatial gradient, with the highest concentrations above 0.9 mg/L observed in WCA2A and the northern portion of the Refuge, along with locations in the Park closest to the L67 extended canal (Figure 32, right). The median for all 116 sampling sites was 0.77 mg/L. Dissolved nitrite, nitrate and ammonia accounted for a very small amount of the TN (median = 2%). During WY15, TN concentration varied greatly at water control structures, depending upon proximity to the EAA. The WY15 flow-weighted mean annual TN entering the Park was 1.15 mg/L, as compared to 5.46 mg/L for the Refuge. The annual median TN interior marsh concentrations for the Refuge, WCA2, WCA3 and Park were 1.1, 1.6, 1.3 and 1.1 mg/L, respectively (Julian et al. 2016a).

Surface water nitrogen gradients throughout the Everglades have been reported since the 1970s. During 1978-82, the five-year mean nitrate concentration entering the Park in western Shark River Slough was 0.012 mg/L, as compared to 0.938 mg/L at the S8 structure in the Miami Canal which was discharging untreated stormwater from the EAA into WCA3A (Matraw et al. 1987). For 1978-87, the mean TN concentration at pumps discharging stormwater from the EAA were 3.4-6.0 mg/L, with inflows to the Park at 2.0 mg/L (Scheidt

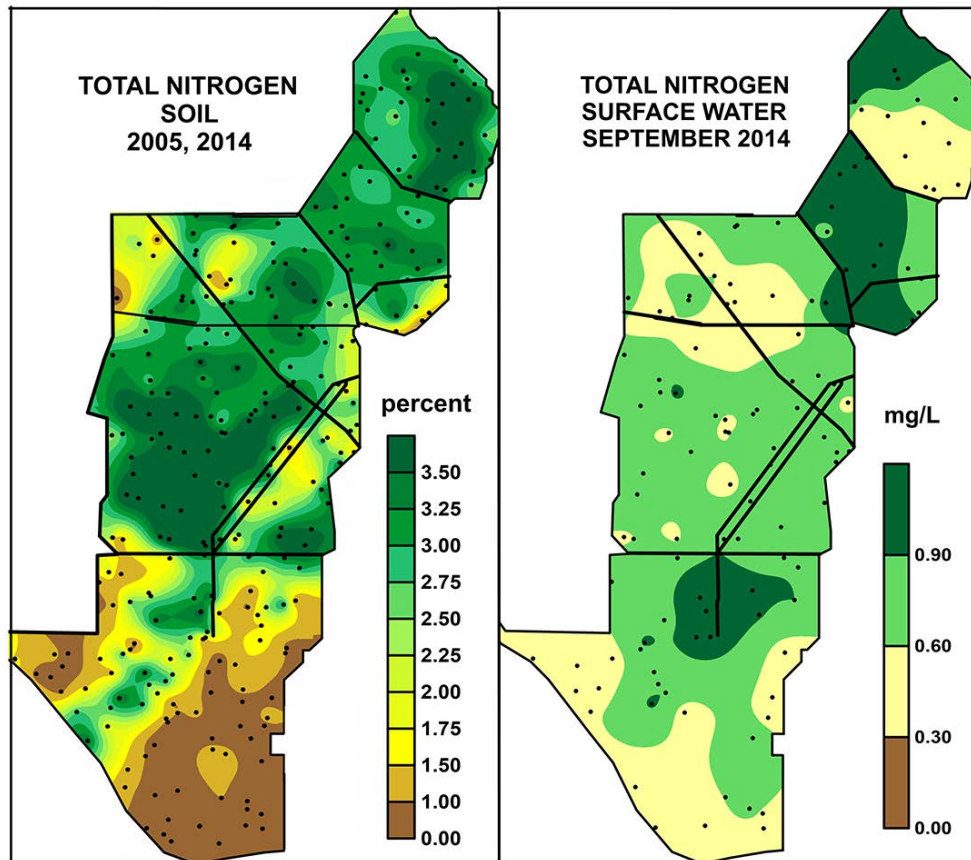
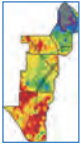


Figure 32. REMAP soil total nitrogen (percent) during 2005 and 2014 (left), and surface water total nitrogen (mg/L) during September 2014 (right).

et al. 1989). A decreasing trend in TN throughout the Everglades during WY79-WY15 has been reported, especially at inflows to the Refuge (-0.14 mg/L/WY) (Julian et al. 2016a).

During WY15 the inflows to STAs 1E, 1W, 2, 3/4 and 5/6 had flow-weighted mean TN concentrations of 2.4, 2.8, 2.5, 2.9, and 1.6 mg/L, respectively, while the outflow concentrations were 1.6, 1.8, 1.6, 1.5 and 1.4 mg/L. The STAs removed a minimal to moderate amount of TN, with WY15 treatment efficiencies of 13% to 49%. The STAs removed most of the nitrite plus nitrate, which was a small portion of TN (SFWMD 2016b). The five-year TN treatment efficiency for STA-1W was 26%, as compared to 79% for TP (Gu et al. 2006).

The median TN content of soils sampled during REMAP 2005 and 2014 was 2.9% ($n=344$, Figures 32-33). Content greater than 3.5% tended to occur in the highly organic peat soils found in the interior of the Refuge and the longest hydroperiod portion of southern WCA3A. In contrast, the marl soils of the Park generally have a TN content of <1.5%. These REMAP data have the same spatial gradients documented throughout the Everglades by SFWMD in 2003 (Orem et al. 2014b, Osborne et al. 2015), and the Park

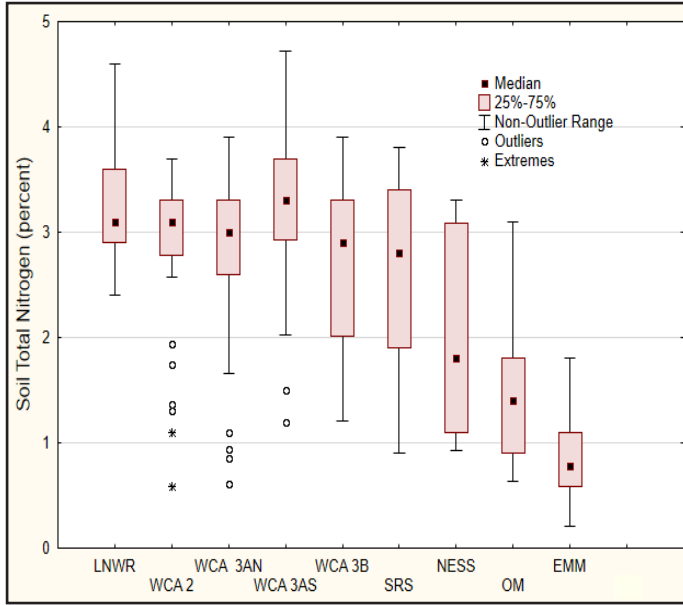
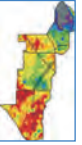
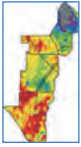


Figure 33. Soil total nitrogen concentration (percent) by subarea, 2005 and 2014.

results are consistent with the SFWMD results at 342 locations (Osborne et al. 2011b). The peat soils of the EAA, which originated from decomposing Everglades sawgrass prior to drainage in the 1900s, also have a TN content of about 3% (Inglett et al. 2011). Soils within STA2 and STA3/4 have mean TN content of 2.8% and 2.4% (Pietro and Ivanoff 2015). The major source of agricultural nitrogen in the EAA is the soil itself. No fertilizer additions of nitrogen are necessary for sugarcane and minimal additions are necessary for vegetables (de Camargo Santos 2020, Morgan et al. 2009). Drainage water from the EAA has been reported to export TN at rates ranging from 30-46 kg N/hectare/year (Porter and Sanchez 1994) and 12-40 kg N/hectare/year (Gilbert and Rice 2006).

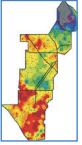


Specific Conductance

Specific conductance is an indirect measure of the overall concentration of dissolved ions or minerals in water, and is defined as the electrical conductance of 1 cubic centimeter (cm^3) of a solution at 25 degrees Celsius. The terms “specific conductance,” “electrical conductivity,” or simply “conductivity” have been used interchangeably in recent decades to report the same measurement. The units of electrical conductivity are mhos per centimeter (mhos/cm), which are equivalent to Siemens per centimeter. Pure water has a very low electrical conductivity of a few hundredths of a micromhos per centimeter (ie., less than $0.05 \mu\text{mhos/cm}$) (Hem 1985, USGS 2019). Specific conductance provides information about the total dissolved ion content of water, but not the ion composition. The terms ‘soft water’ and ‘hard water’ are used to describe waters containing relatively low or high concentrations of dissolved ions. As the concentration of dissolved ions increases, so does the conductivity. In the Everglades, conductivity is useful for understanding the source of water and its flow path.

The 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 to several thousand $\mu\text{mhos/cm}$. From the 1940s to 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 (Miller 1988). During 1997-2003, the median conductivity at 10 farm canals within the EAA ranged from 770-1670 $\mu\text{mhos/cm}$, as compared to 600 $\mu\text{mhos/cm}$ for Lake Okeechobee. The highest values within the EAA occur in the eastern portion within the S5A and S6 basins. During the wet season, farm canals upstream of the Refuge have conductivities above 1200 $\mu\text{mhos/cm}$ due to the seasonal input of groundwater during drainage pumping for flood control operations (Bhada et al. 2014). During 1974, when water from the EAA was pumped north into Lake Okeechobee, surface water conductivity was about 1000-1400 $\mu\text{mhos/cm}$ in canals within the EAA, whereas lake conductivity decreased at a gradient to about 500-800 $\mu\text{mhos/cm}$ toward the interior (Brezonik and Federico 1975). Conductivities in canals surrounding the Refuge and in the EAA are higher due in part to the upward migration of residual (connate) seawater (Miller 1988). The major ions in EAA farm canal water contributing to conductivity are chloride, sulfate, carbonate, sodium and calcium (Chen et al. 2006).

Pronounced spatial gradients in surface water conductivity, sulfate and chloride throughout the canal and marsh system vividly demonstrate that the canal system can be a conduit for transport of degraded water. Conductivity varies with the number and types of ions in solution. The water in the interior marsh of the Refuge is soft, slightly acidic (median pH = 6.1, REMAP data from September 2014), and strongly influenced by rainfall (precipitation pH=5.1, NADP 2014a). The limestone (calcium carbonate) substrate underlying the Refuge is overlain by several feet of peat soil, 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 (median = 7.4). In the shorter hydroperiod portions of the Park there is little soil, so surface water has higher ionic content



because it is influenced by the limestone substrate (Figures 53 and 58). 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 the Everglades because it is one of the determinants of the composition of periphyton communities, which play a critical role in food webs, habitat, soil formation and water quality (McCormick et al. 2011).

REMAP data document pronounced conductivity gradients and transport of high conductivity water by canals well into the Everglades marsh and the Park (Figures 34-35, Stober et al. 1998, Scheidt et al. 2000, Scheidt and Kalla 2007). These gradients are due to the relative influence of rainwater, groundwater, and stormwater inflows, and they indicate pathways of water flow throughout the canal-marsh system and the extent to which the water management infrastructure and operations influence water quality. Precipitation in the Everglades has very low ionic content, with 2014 average annual specific conductivity of 10.0 $\mu\text{mhos/cm}$ within the Park (NADP 2014a). In contrast, the conductivity of water discharged from the EAA into STAs 1E, 1W and 2 during the September 2014 REMAP sampling was 1000-1200 $\mu\text{mhos/cm}$, with STA5/6 having the lowest inflow conductivity of about 540 $\mu\text{mhos/cm}$. The highest marsh conductivities of about 900 $\mu\text{mhos/cm}$ were within the Refuge and WCA2 near the canals due to proximity to the EAA and the influence of canal water and groundwater. The WY15 annual flow-weighted mean conductivity in water discharged from the Stormwater Treatment Areas (STAs) into the Refuge was 930 $\mu\text{mhos/cm}$ from STA1E and 863 $\mu\text{mhos/cm}$ from STA1W. The average conductivity in annual discharges from the other STAs were: STA2 887 $\mu\text{mhos/cm}$

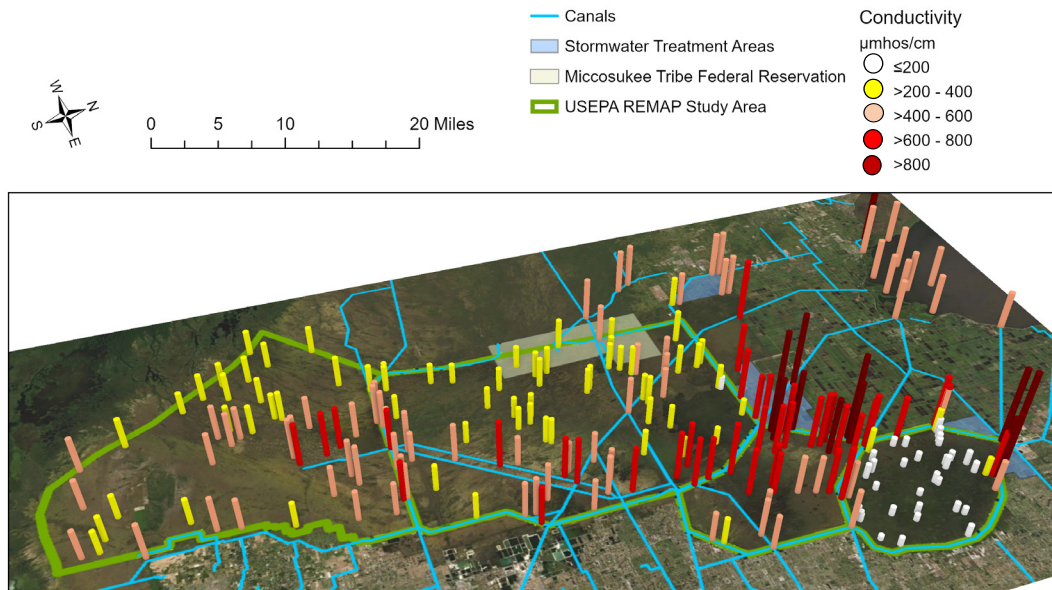
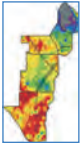


Figure 34. Surface water conductivity (specific conductance, $\mu\text{mhos/cm}$) during September 2014 at 116 REMAP marsh stations. Also shown are SFWMD data for 11 locations in Lake Okeechobee and 70 locations in the Everglades marsh (geometric mean), and 32 water control structures in canals (geometric mean when flowing) including selected STA inflows and outflows.



cm, STA3/4 735 $\mu\text{mhos/cm}$, and 456 $\mu\text{mhos/cm}$ from STA5/6. As water passes through the STA treatment wetlands, designed and operated for phosphorus removal, there is little change in conductivity. Conductivity in the STA discharges was within 10% of the inflows, except STA1E where the discharge conductivity was 21% higher than in the inflow (SFWMD 2016b).

Lower wet season conductivity in the interior of the Refuge (about 70 $\mu\text{mhos/cm}$) and the western portion of WCA3A (about 250-300 $\mu\text{mhos/cm}$) reflect the greater influence of rainwater as compared to canal water (Figures 35 and 36). 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 flows (Scheidt et al. 2000). From 1959 to 1974, as inflow to the Park at Shark River Slough changed from being dominated by marsh sheetflow to canal discharge at the new S12 structures, wet season mean marsh conductivity rose from 270 to over 500 $\mu\text{mhos/cm}$ (Flora and Rosendahl 1982a, 1982b). During 1978 to 1982, conductivity varied spatially such that at structure S12A, a gated spillway that discharges water into the Park at western Shark Slough, conductivity averaged 303 $\mu\text{mhos/cm}$, as compared to 1184 $\mu\text{mhos/cm}$ entering WCA3A in the Miami Canal at the S8 structure 39 miles to the north (Matraw et al. 1987).

Conductivities observed in WCA3 and WCA2 during the 2014 REMAP sampling were lower than those observed during 2005. The maximum in WCA2A during 2014 was 780 $\mu\text{mhos/cm}$, as compared to 1423 $\mu\text{mhos/cm}$ in 2005 (Figure 35). WCA2 had a median of 1041 $\mu\text{mhos/cm}$ in 2005 versus 676 $\mu\text{mhos/cm}$ in 2014, and the Refuge had a median of 151 $\mu\text{mhos/cm}$ in 2005 versus 77 $\mu\text{mhos/cm}$ in 2014.

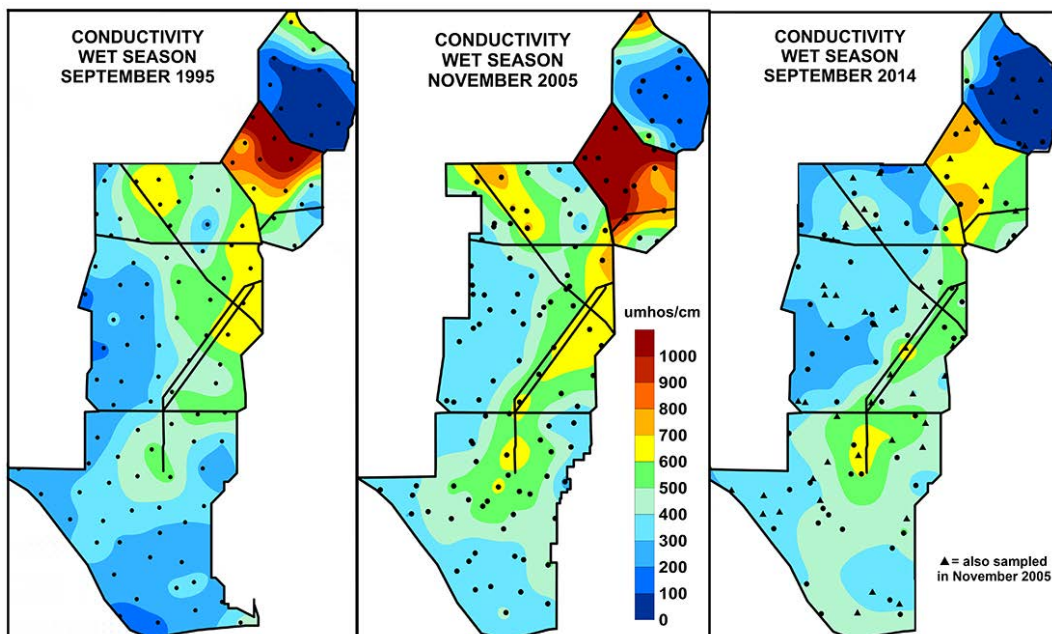


Figure 35. Surface water conductivity ($\mu\text{mhos/cm}$) in the marsh during REMAP September 1995, November 2005 and September 2014 wet season sampling events.

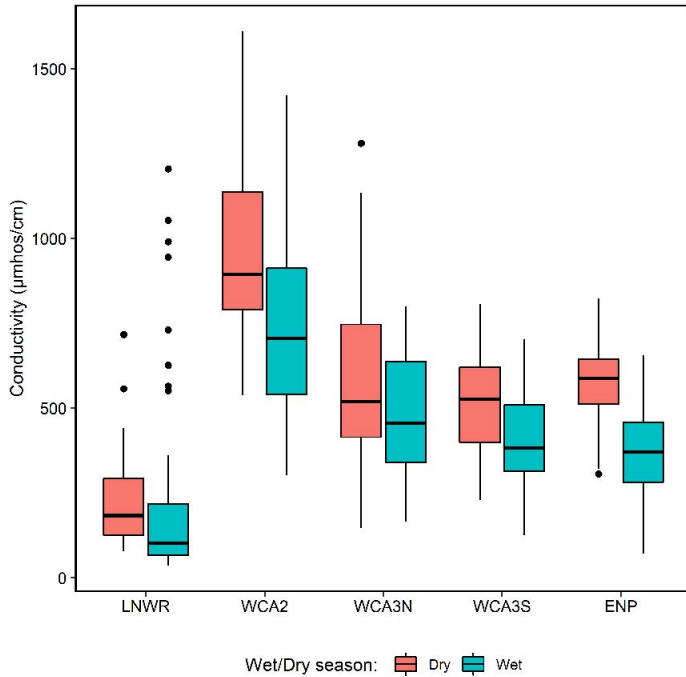
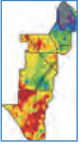
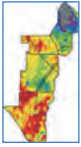


Figure 36. Box and whisker plot of surface water conductivity ($\mu\text{mhos/cm}$) during the wet and dry seasons for all REMAP marsh sampling events.

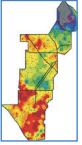
Surface water conductivity, chloride, sulfate and dissolved organic carbon were all lower in 2014 than in 2005. These differences could be explained by less discharge from the EAA into the Everglades preceding the 2014 sampling. September 2014 REMAP data indicate that as expected marsh conductivity is correlated with surface water chloride, sulfate and dissolved organic carbon [Spearman rank-order correlation coefficients of 0.95, 0.71, and 0.65 respectively, $p < 0.001$ (Kalla and Scheidt 2017)]. A long-term decrease in the conductivity at inflows to the Refuge and WCA2A since 1979 has been reported (Julian et al. 2016a), as has a decrease in conductivity from 1977 to 2005 at some of the structures that release water into the Park at Shark River Slough (Fan et al. 2010).

The discharge of high conductivity water into the Refuge marsh has been a concern since the 1970s, when the penetration into the Refuge marsh of highly mineralized water at 10 to 20 times background conditions was documented (Gleason and Spackman 1974, McPherson et al. 1976). Concern was raised about the impacts of this mineralized water on Refuge biota, such as periphyton, that are adapted to low conductivity, soft water conditions (Gleason and Spackman 1974, Gleason et al. 1975a). Florida's Class III water quality criterion for conductivity that applies to the Everglades is: "shall not be increased more than 50% above background or to 1275 micromhos/cm, whichever is greater" (Chapter 62-302.530(22) F.A.C). In the annual South Florida Environmental Report, Florida reported conductivity excursions for 2014 that exceed the Class III criterion and are of concern for inflows to the Refuge and the WCA2A marsh (Julian et al. 2016a). The Park and Refuge are also Outstanding Florida Waters, which 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 less than 100 $\mu\text{mhos/cm}$. Highly mineralized water penetrates several kilometers into the Refuge marsh (Harwell et al. 2008; Surratt et al. 2008; McCormick et al. 2011). Data from transects in the Refuge marsh downstream of the STAs indicate that during WY15 water entered the Refuge downstream of STA1E at about 1000 $\mu\text{mhos/cm}$ (annual geometric mean), and dropped to 200 $\mu\text{mhos/cm}$ at about 3.5 kilometers (km) into the marsh.



Water entered the Refuge from STA1W at about 800 $\mu\text{mhos/cm}$, and dropped to 200 $\mu\text{mhos/cm}$ by about 1.0-2.5 km into the marsh, depending upon the transect. In contrast, water entered WCA2A at about 900 $\mu\text{mhos/cm}$ and by 5 km into the marsh there was no decrease along the three transects (SFWMD 2016b).

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 (Browder et al. 1993, Sklar et al. 2005b, McCormick and Harvey 2007, McCormick 2011, McCormick et al. 2011, Gaiser et al. 2011, Gottlieb et al. 2015). Periphyton communities in the Refuge tend to be attached to plants (epiphytic) and are dominated by desmid and diatom species, while the extensive periphyton mats (Figure 63 and 64) in hard water portions of the Everglades are dominated by calcium-precipitating cyanobacteria with a high calcium carbonate content (McCormick and Harvey 2007; McCormick et al. 2011). CERP developed 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 (RECOVER 2007). A restoration goal is that the natural soft, low-conductivity surface water will be maintained in the Refuge, while the hard, higher conductivity water consistent with natural background levels in much of the rest of the Everglades will also be maintained. Everglades restoration should take into consideration ways of minimizing the intrusion of mineral-rich water into the Refuge interior (Newman and Hagerthey 2011). However, given the inevitable groundwater-surface water interaction due to the presence of canals, elevated surface water conductivity is unavoidable to some extent. Water management operations have been developed to help reduce canal water intrusion in the Refuge interior (Surratt et al. 2008).



Chloride

Chloride is an ion that is found in surface water and groundwater. Chloride ions can come from sodium chloride or from other chloride salts. Saltwater has very high natural concentrations of chloride. In coastal areas, estuarine waters contain more chloride than freshwater due to the influence of saltwater. Chloride is a conservative ion, meaning its concentration does not readily change. Therefore, chloride can be a useful indicator of a water’s source.

The concentration of chloride varies greatly throughout the Everglades depending upon the relative influence of rainwater, groundwater and stormwater. During 2014, precipitation in the Everglades had a precipitation-weighted annual chloride concentration of 1.0 milligram per liter (mg/L) (NADP 2014a). (The chloride concentration was measured in weekly samples of precipitation, and when calculating the average annual chloride concentration, the chloride results are weighted by the volume of precipitation during that week in order to get an accurate annual average.) During the September 2014 wet season sampling, the lowest surface water chloride concentrations of <15 mg/L were observed in the interior of the Refuge and the western portion of the Park and southwestern WCA3 away from canal inflows. The highest concentrations, exceeding 100 mg/L, were observed at some STA inflows and discharges and in the Refuge and WCA2A marshes near inflows (Figures 37-38). The median concentration in the Refuge was 12 mg/L, as compared to 83 mg/L in WCA2. While these spatial patterns are similar to those observed in 2005, the 2014 medians

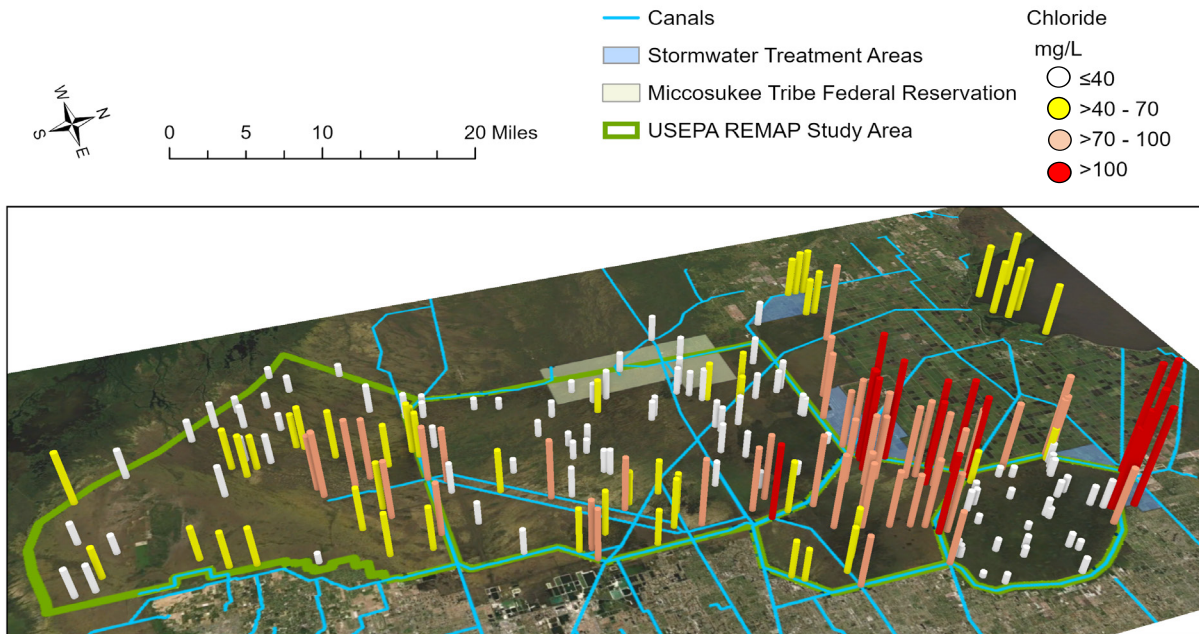
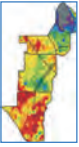


Figure 37. Surface water chloride concentration (mg/L) during September 2014 at 116 REMAP marsh stations. Also shown are SFWMD data for 6 locations in Lake Okeechobee, 75 locations in the Everglades marsh and 32 water control structures in canals (geometric mean when flowing) including selected STA inflows and outflows.



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

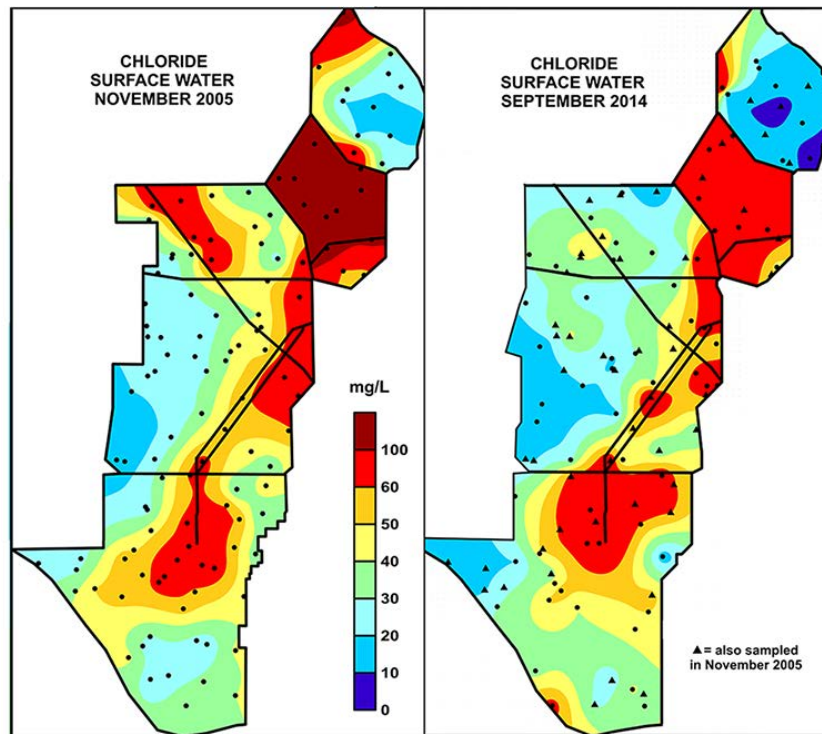


Figure 38. Surface water chloride (mg/L) in the marsh during the REMAP November 2005 and September 2014 wet season sampling events.

were lower (2005 Refuge median 26 mg/L and WCA2 median 140 mg/L, Scheidt and Kalla 2007). Chloride concentrations in the northern portion of WCA3A near the Miami Canal were also lower in 2014 than 2005, and may reflect somewhat greater discharge from the north and influence of canal water in 2005 (121,788 ac-ft at inflows into WCA3A at S8 during October to November 2005 versus 106,358 ac-ft in August to September 2014, Abtew et al. 2007; Abtew and Ciuca 2016). Over the duration of REMAP sampling events, wet season chloride concentrations within each subarea were lower than dry season concentrations, presumably because of the diluting effect of rainfall (Figure 39).

The groundwater chloride concentration in the shallow aquifer within the EAA at a depth of 20 feet is typically reported between 100-200 mg/L. The chloride concentration within this shallow aquifer increased

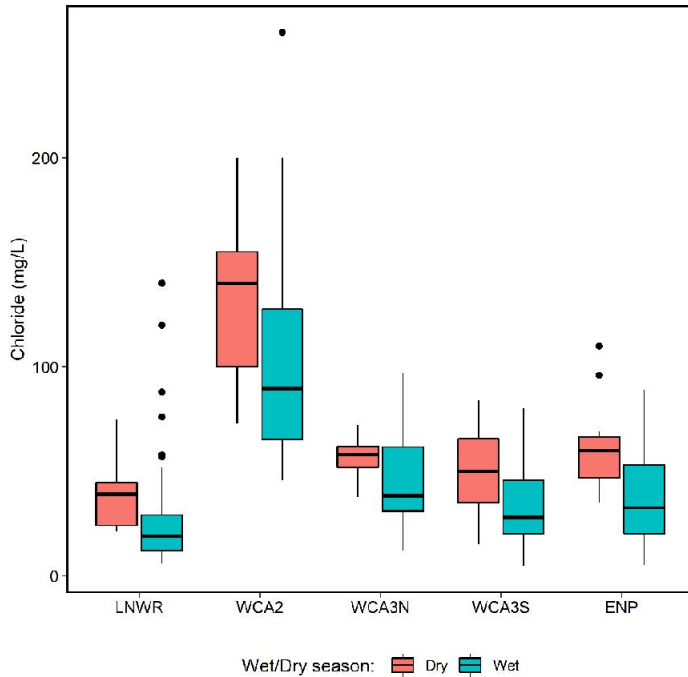
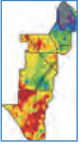
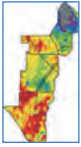


Figure 39. Wet and dry season surface water chloride (mg/L) by subarea in the marsh during all REMAP sampling events.

from the 1940s to the 1980s due to the upward migration of groundwater in response to pumping for flood control (Miller 1988). During 1999-2003 the median chloride concentration at 10 farm canals within the EAA was 72-174 mg/L (Chen et al. 2006). Chloride concentrations reported for 1972-73 in the Hillsboro Canal and the downstream WCA2 marsh both averaged about 170 mg/L, with some concentrations as high as 500 mg/L (Gleason 1974). From 1959 to 1974, as inflow to the Park at Shark River Slough changed over time from being dominated by marsh sheetflow to canal discharge at the new S12 structures, canal chloride concentration rose from about 20 mg/L to 60 mg/L (Waller 1982).

Pronounced gradients in chloride concentration within the Refuge and WCA2 marshes have existed since the early 1970s (Gleason 1974, Gleason et al. 1975b). From 2000-06, marsh stations within 1 km of the canal had median chloride concentrations of 100-130 mg/L, as compared to about 20 mg/L for marsh stations farther from the canal. A hydrodynamic and constituent transport modelling effort found that interior marsh chloride originated from pumped inflows rather than rainfall (Chen et al. 2012). Chloride concentrations in the Refuge perimeter canal during 1995-2007 ranged from about 50-170 mg/L, while concentrations in the interior marsh typically ranged from 10-50 mg/L, but exceeded 100 mg/L during particular events. Chloride was used as a conservative surface water constituent to develop a water quality and hydrology model for the Refuge. Pumped inflow was found to be the dominant factor responsible for the substantially increased chloride and sulfate concentrations in the marsh (Wang et al. 2012). Chloride is one of the constituents of highly mineralized water that is of ecological concern to the naturally soft-water Refuge.

The STA wetland treatment systems that are designed and managed to remove phosphorus generally do not remove a large proportion of the chloride. The chloride concentration in the STA discharges into the Refuge from STA1W generally varied between 100 to 200 mg/L from 1994-1999 (Gu et al. 2006). For WY06, during the 2005 REMAP sampling, STA 1W, STA 2, STA 3/4, and STA 6 discharged dissolved chloride at concentrations of 142, 157, 73 and 22 mg/L respectively, and outflow concentrations generally were only slightly lower or higher than inflow concentrations (Pietro et al. 2007).



Sulfur

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. Sulfate is a natural ingredient of rainfall, surface water and groundwater. The form of sulfur that exists in the environment where there is no oxygen is the reduced form, sulfide, which is associated with sulfate reduction by anaerobic bacteria. Sulfur is applied to condition soils in the EAA for crops (Morgan et al. 2009). Sulfur is of interest in the Everglades for three reasons: sulfate and sulfide are associated with mercury methylation and subsequent biomagnification in gamefish and wildlife (Fink and Rawlik 2000, Jeremiason et al. 2006, Orem et al. 2019, Pollman 2014, 2019; Rumbold 2019a); elevated sulfate can mobilize phosphorus in some water bodies (Smolders et al. 2006, Lamers et al. 1998, Lamers et al. 2002, Beltman et al. 2000); and sulfide at elevated concentrations can be toxic to or adversely affect plants (Smolders et al. 2006, Lamers et al. 1998, Lamers et al. 2002; Li et al. 2009) and animals (USEPA 1986). Because of these ecological concerns CERP adopted a restoration performance measure for surface water sulfate: maintain or reduce sulfate concentration to 1 milligram per liter (mg/L) or less throughout the Everglades marsh (RECOVER 2007).

Florida does not have specific water quality criteria for sulfate or sulfide in the Everglades, and USEPA does not have a recommended surface water criterion for sulfate. For sulfide in surface water, USEPA recommends a continuous concentration criterion of less than 0.002 mg/L for protection of aquatic life (USEPA 1986). Florida water quality standards require 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.” (Chapter 62-302(62) F. A. C.). This is referred to as the ‘free from’ requirement. In addition, Florida also designated the Park and Refuge as Outstanding Florida Waters, requiring that the water quality that existed as of March 1, 1979 be maintained.

Sulfate concentration varies throughout the Everglades marsh depending upon proximity to the EAA and canals, and the relative influence of rainwater, stormwater and groundwater. Pronounced marsh and canal surface water sulfate gradients have been documented independently by USEPA REMAP during 1993 to 1996, 1999 and 2005 (Scheidt et al. 2000, Stober et al. 2001b, Scheidt and Kalla 2007), USGS (Orem et al. 2011) and SFWMD (Julian et al. 2016b). Earlier studies documenting sulfate gradients during the 1970s are summarized in Scheidt and Kalla (2007). Surface water sulfate is highest during the wet season with the movement of water throughout the Everglades for flood control. Elevated sulfate levels in 2014 followed this same landscape pattern (Figures 40-42). Concentrations varied from <0.022 mg/L (the analytical laboratory method detection limit (MDL) in 2014) at marsh locations away from canals, to 75 mg/L and 80 mg/L at the inflows to STAs 1W and 1E near the Refuge (Figure 40). Concentrations in southern Lake Okeechobee averaged 40 mg/L. Figure 41 shows marsh stations sampled by REMAP during the 1995, 2005 and 2014 wet seasons. The highest marsh concentrations are at locations that are proximate to canals or stormwater flows from the EAA. Concentrations in the Everglades progressively decrease to the south and west. These landscape patterns indicate that the canal system delivers sulfate from the north into Everglades marshes,

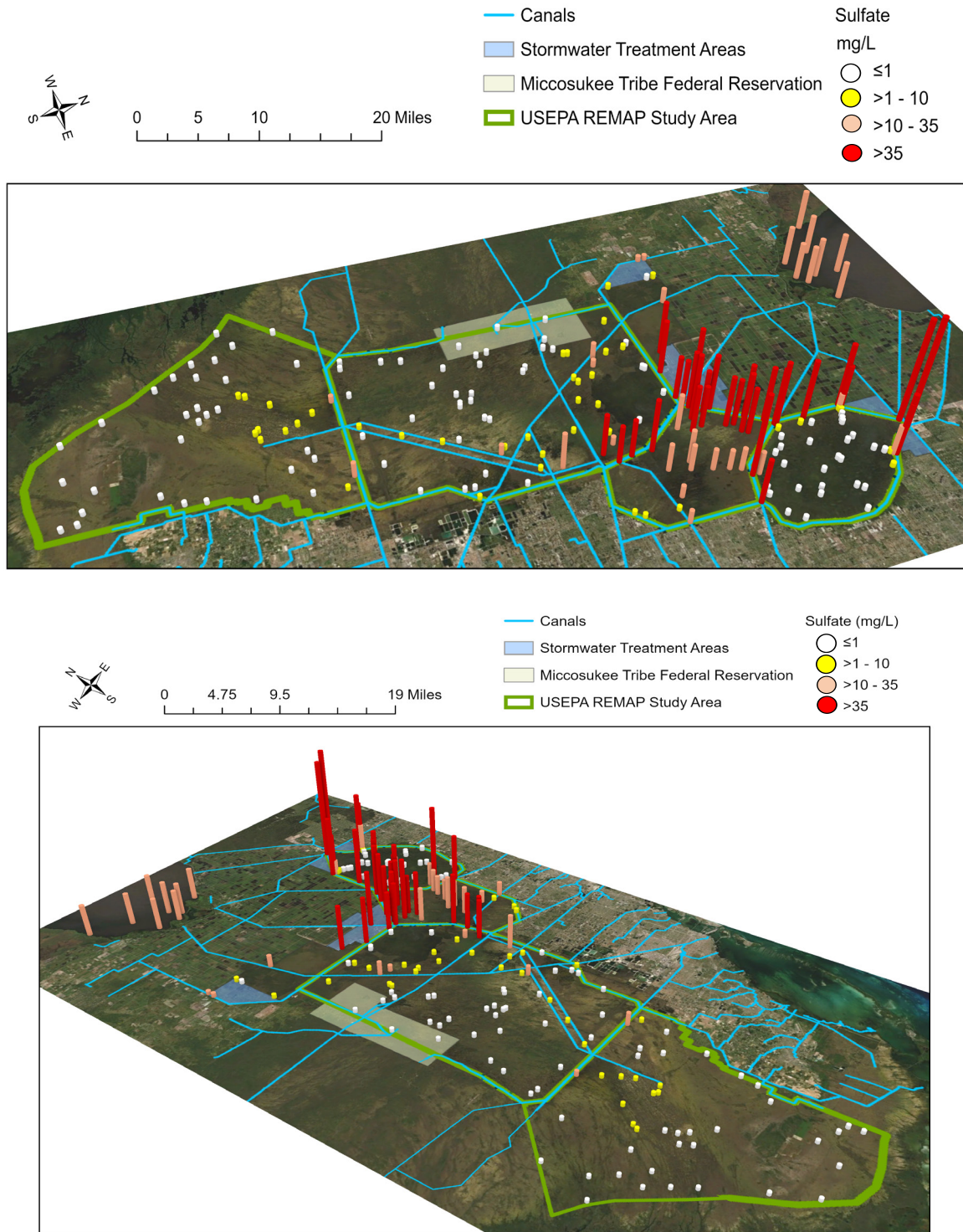
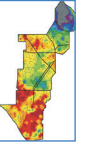
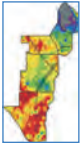


Figure 40. Sulfate (mg/L) in surface water during September 2014 at 116 REMAP Everglades marsh stations. Also shown are SFWMD data for 8 locations in Lake Okeechobee, 60 locations in the Everglades marsh (geometric mean) and 16 water control structures (geometric mean when flowing) in canals, including selected STA inflows and outflows. The top view is from the east, the bottom view is from the west.



with penetration into the Shark River Slough marsh within the Park (Figure 40). The influence of canal water flowing into the marsh in the wet season was more apparent in 1995 and 2005 than in 2014.

Sulfate concentrations in rainfall and interior marsh locations away from canals are lower. The annual precipitation-weighted sulfate concentration in rainfall within the Park for 2014 was 0.69 mg/L (NADP 2014a). It was less (0.47 mg/L) during August and September of 2014 around the time of the REMAP sampling (NADP 2014b). During the September 2014 REMAP sampling, interior portions of the Park, Refuge and WCA 3 that are most influenced by rainfall had 21 stations with sulfate concentrations in surface water reported at the analytical laboratory MDL of about 0.02 mg/L (Figures 40-41), indicating that the true concentration may be even lower. There are 72 stations sampled in 2014 in Figure 41 within the <2 mg/L isopleth that were <1 mg/l, with a median concentration of 0.08 mg/L.

Sulfate is one of the constituents of highly mineralized water that is of ecological concern to the naturally soft-water Refuge. There are pronounced surface water sulfate gradients from the canals to the Refuge interior marsh (Harwell et al. 2008). Water and soil chemistry data collected along an east-west transect show an extensive zone of sulfur enrichment associated with episodic canal-water intrusion. Natural background concentrations are <1 mg/L for surface water sulfate and <1% for soil sulfur. Concentrations are elevated to as high as 9 mg/L and 2% at sites within about 5 km of the western and eastern rim canals (McCormick et al. 2011). Soil sulfur is lower in the Refuge interior, with much higher concentrations along the marsh periphery (Osborne et al. 2011a). Pumped inflow is the dominant factor responsible for the substantially

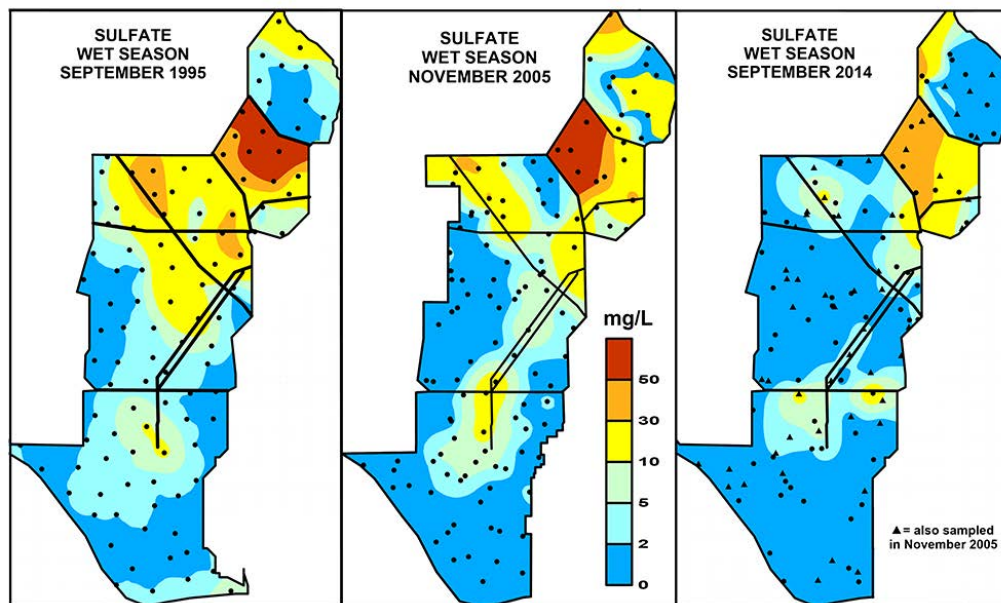
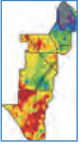


Figure 41. REMAP surface water sulfate concentration (mg/L) during September 1995 (left), November 2005 (center) and September 2014 (right).



increased sulfate and chloride concentrations in the interior marsh (Wang et al. 2012), rather than atmospheric deposition (Wang et al. 2009). Residual seawater that contains high sulfate also influences canal sulfate concentrations in the vicinity of the Refuge and WCA2A (Pollman 2012).

The wetland STAs designed and managed to remove phosphorus remove little sulfate (Orem et al. 2011). During WY15, for the STAs the flow-weighted sulfate inflow and outflow concentrations, and percent removal were as follows: STA1W 68, 66 mg/L, 3%; STA1E 56, 57 mg/L -3%; STA2 51, 45 mg/L, 12%; STA3/4 48, 46 mg/L, 5%; and STA5/6 10, 2 mg/L, 77% (SFWMD 2016b). Sulfate removal by the STAs was about 10% or less, with the exception of STA5/6 which had a much lower inflow sulfate concentration. STA1W exhibited moderate removal of sulfate from 1994-99 (Gu et al. 2006). The eastern EAA (the S5A, S2 and S6 basins) has consistently had the highest concentrations of sulfate in groundwater and surface water. If the high sulfate within the STAs mobilizes phosphorus, this may hinder phosphorus removal by STAs, especially for STAs 1W, 2 and 3/4.

The concentration of sulfate in Everglades groundwater is higher than surface water natural background levels. Sampling of the surficial aquifer underlying the EAA at about 20 locations in 1983-84 found sulfate concentrations of 25-580 mg/L at a groundwater depth of 45 feet, about 20 feet below the depth that the major canals penetrate. These high concentrations may be due in part to residual seawater (Miller 1988). The highest concentrations were in the eastern EAA in the area of the S-2 and S-6 basins. In 1976-77, sulfate was 20-490 mg/L in shallow groundwater in the EAA, with mean concentrations of 153 mg/L beneath sugarcane and

199 mg/L beneath vegetables. The mean surface water concentrations ranged from 40-459 mg/L (CH2MHILL 1978). In contrast, the median groundwater concentration in 189 wells tapping the Biscayne Aquifer was 17 mg/L (Radell and Katz 1991). The Biscayne Aquifer is the shallow, unconfined, highly-permeable aquifer underlying the Everglades and southeast Florida.

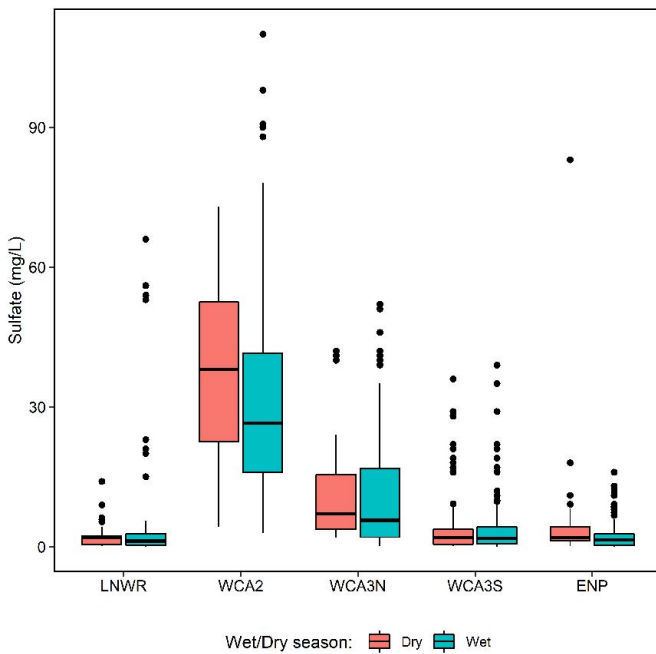
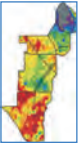


Figure 42. REMAP surface water sulfate concentration (mg/L) by subarea during the wet and dry seasons for all REMAP marsh sampling events.

Agricultural sulfur (S) has been applied to EAA soils for various purposes. EAA soils have been prone to copper deficiency, which has been addressed by treatment with copper sulfate. Magnesium has been supplemented by the use of fertilizer blends containing potassium-magnesium sulfate (Anderson 1990). 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 (Coale 1994, Schueneman and Sanchez 1994). It has been reported that grower S application rates are lower than recommended rates (Schueneman, 2001). Application rates have been estimated at 10 pounds per acre (lbs/ac) to sugarcane and 78 lbs/ac to vegetables (CH2MHILL 1978). Recent agricultural studies suggest that S application may have minimal benefits for increasing nutrient availability (Ye et al. 2009, 2011a). As EAA soils subside, the pH of the remaining soil tends to increase, which may result in a need for higher S application rates (Ye et al. 2011b). This could increase S export to the Everglades (Ye et al. 2010).

Investigators analyzing sulfur concentrations and isotopic ratios for rainwater, EAA groundwater, and EAA fertilizer concluded that excess sulfate in the Everglades originates from canals draining the EAA (Bates et al. 2002). The sulfate concentration and isotopic data appear to exclude rainwater and some ground water as major contributors. Isotopic evidence implicates agricultural applications as a major contributor to the sulfate load. This fertilizer could be recent additions, legacy deposits, or both. However, EAA groundwater and oxidation of agricultural soil may also contribute sulfate (Bates et al. 2002). It has been reported that, based on isotopic composition, groundwater is not a major source of sulfate to surface water in WCA2A (Gilmour et al. 2007).

Sulfate in Lake Okeechobee was about 40 mg/L from 1975-2001, and declined over the last three decades (James and McCormick 2012). About 97% of the sulfate in Lake Okeechobee originates from the watersheds that discharge to the lake, including backpumping from the EAA, with rainfall and atmospheric deposition contributing only 3% of the sulfate load. Lake water provides about 20% of the sulfate to the EAA, and smaller loads to the Everglades. There are several mass balance estimates of S inputs to the EAA and outputs to the Everglades (Corrales et al. 2011, Gabriel et al. 2014a, Landing 2015). Sulfur outputs to the Everglades either equal or exceed inputs to the EAA, depending upon assumptions (see summary in Landing 2015). The importance of controlling sulfate to the lake increases if more lake water is moved south to the EAA for water supply and environmental enhancement because increased flow from the lake could result in higher loads to the EAA and Everglades (James and McCormick 2012), especially since STAs do little to remove sulfate.

Elevated surface water sulfate concentrations were found during all REMAP sampling events, with varying extent. Sulfate was highest during the 1995 REMAP wet season sampling event, lower in 2005 and lowest in 2014 (Figures 41, 43-44). The laboratory analytical MDL for sulfate improved greatly between 1995 and 2005, from 2.0 mg/L down to 0.02 mg/L, so the apparent differences between years are exaggerated. In order to account for this, the minimum value for all years was changed to the highest MDL of 2 mg/L (Figure 43). Despite these data being left-censored at 2 mg/L due to laboratory MDLs, and the overlap of confidence intervals, all three CDF curves are different (Wald F, $p < 0.05$). The Park, the Refuge, and WCA3 had less sulfate in surface water in 2014 than in 2005 (Wald F, $p < 0.02$). Based on the CDF of REMAP data, during September 2014 the proportion of the Everglades marsh where sulfate exceeded the 1.0 mg/L CERP restoration goal was $37.1 \pm 6.0\%$, lower than $57.3 \pm 6.0\%$ in 2005.

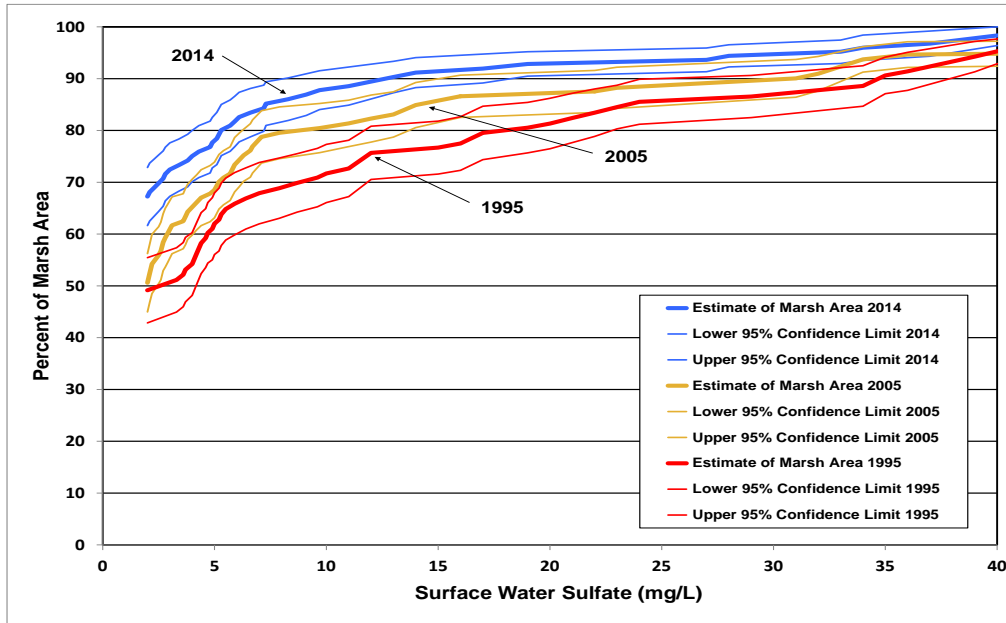
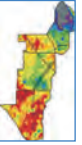


Figure 43. Cumulative Distribution Function (CDF) showing surface water sulfate concentration (mg/L) estimates of marsh area for 1995, 2005 and 2014 wet season REMAP samples. The areas reflect different conditions (Wald F test).

A significant decreasing trend for wet (rainfall) and dry atmospheric deposition of sulfate has been reported from WY95-WY15, the duration of REMAP sampling. Air emissions controls may be a factor in this decrease (Julian et al. 2017a). No overall trends are apparent in annual sulfate at surface water inflows to the Refuge, WCA2, WCA3 or the Park from WY95-WY15 (Julian et al. 2016b). At a marsh location in central WCA3A sampled by USGS from 1995 to 2007, sulfate declined significantly beginning in 1998 and remained below 1.0 mg/L through 2007. The cause for the decline was not known (Orem et al. 2020). The lower surface water sulfate concentration observed by REMAP in 2005 compared to 1995 is not likely due to dilution because the lower concentrations observed during the 2005 wet season occurred in shallower water than in 1995 (Figure 21). Less loading from 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 (Scheidt and Kalla 2007). The lower concentrations in WCA2A during 2014 as compared to 2005 are suggestive of less stormwater discharge. Concentrations in water may vary within the wet season depending upon particular rainfall and discharge events, so the sulfate concentrations observed during a two-week REMAP sampling snapshot may not represent conditions observed during other weeks in the same wet season. This transient surface water quality characteristic is also applicable to other water quality constituents such as nutrients and ions. USGS found that from 2008-2013 sulfate concentrations within the Park at SRS were influenced by canal water, and there was high interannual variation due to flow (Maglio et al. 2015).

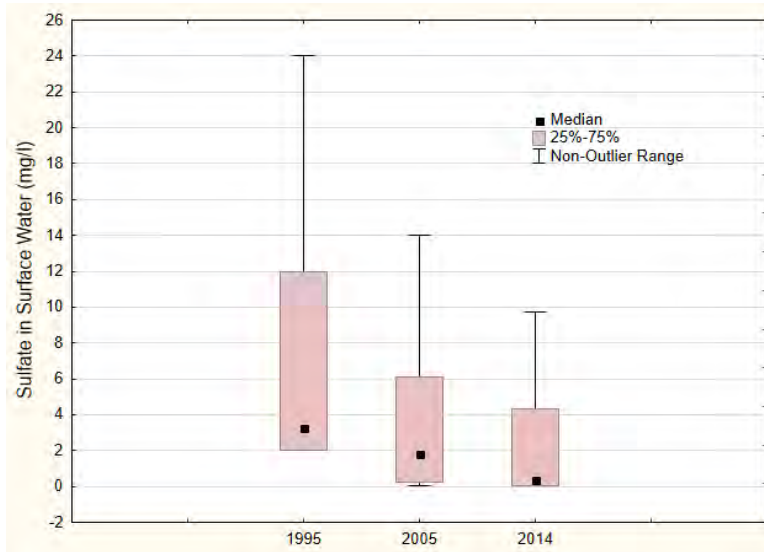
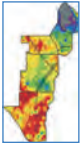


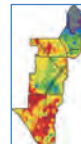
Figure 44. Box-and-whisker plots of sulfate in surface water (mg/L) in the 1995, 2005 and 2014 wet season REMAP samples by year. In 1995 the lowest possible value was the MDL of 2 mg/L.

Under anaerobic conditions, sulfide is formed from sulfate. Sulfur speciation and isotopic composition of Everglades plant materials suggests that sulfate reduction occurs in the periphyton mat (Bates et al. 1998). Higher sulfide can have the benefit of inhibiting mercury methylation (Jeremiason et al. 2006, Benoit et al. 1999), but it can also have the detriment of being toxic to macrophytes (Lamers et al. 1998). Sulfide levels in Everglades soils within WCA2 are consistent with concentrations that negatively affect sawgrass (Li et al. 2009). Others suggest that P limitation could override effects of sulfide toxicity, although the effect of sulfide accumulation on P-enriched areas is unknown (DeBusk et al. 2015). There

are no water quality criteria for sulfide in pore water.

In 2014, REMAP measured the sulfide concentration in water at the bottom of the surface water profile immediately above the soil (bottom water, Kalla and Scheidt 2017). In 2005, sulfide was measured in the water within the top portion of the soil (pore water). In the Everglades, sulfide in bottom water can be predicted by sulfide in pore water ($r^2 = 0.82$, $p < 0.001$, Kalla et al. 2017). During 2005, sulfide concentration in pore water had pronounced spatial gradients, with concentrations > 5 mg/L in WCA2A. A lab study found that small Everglades sawgrass plants were adversely affected by sulfide at concentrations above 7 mg/L (Li et al. 2009). During 2014 the highest bottom water sulfide concentration in WCA2A was only 0.56 mg/L, and 90% of the values were < 0.1 mg/L. These lower sulfide concentrations are consistent with the lower surface water sulfate concentrations observed in 2014. Bottom water sulfide was correlated with surface water sulfate and dissolved organic carbon (DOC) (Kalla and Scheidt 2017). In 2005, pore water sulfide also was positively correlated with pore water DOC and methylmercury in surface water, periphyton and soil. Fewer correlations observed in 2014 may be due to the much lower range in sulfide concentrations. Others also found that surface water sulfate was positively correlated with porewater sulfide due to reducing conditions favoring conversion of sulfate to sulfide, and porewater DOC significantly influenced porewater sulfide concentrations, suggesting that organic substrate supply could be a factor that affects sulfate reduction (Julian et al. 2016e).

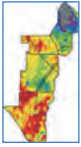
Sulfur has been raised as a concern in Everglades restoration regarding Aquifer Storage and Recovery (ASR), a technology proposed near Lake Okeechobee to help meet the ecological and water supply needs of south Florida and the Everglades. During the wet season surface water is pumped into the aquifer and recovered later during the dry season to supplement water supply. The water recovered from ASR is anticipated



to have high sulfate (200-550 mg/L), which could stimulate microbial sulfate reduction and methylmercury production. Modeling indicates that ASR release would temporarily elevate sulfate concentrations in Lake Okeechobee by 60%, but that this would have little impact on methylmercury production in the lake. The Lake's sandy soils are not conducive to methylation. ASR water released to surface water would have minimal impacts on sulfate loading to the Everglades, primarily due to the much higher sulfate loading from other sources within the EAA. Overall impacts due to increased methylmercury production risk were predicted to be low, although locations in the Everglades near canals or STA discharges could experience significantly higher sulfate loading from ASR and some change in mercury risk (Orem et al. 2014a).

The role of sulfate in the biogeochemical cycling of mercury in the Everglades is complex and has been under investigation since the 1990s. REMAP data from 1995-2005 were used to explore the relationship between mercury in prey fish (mosquitofish) and many biogeochemical analytes by using structural equation modeling. This approach provides a framework for selecting or rejecting hypotheses or assumed relationships using data acquired by observation (empirical data). The role of sulfate was found to be complex in terms of its total effect on mosquitofish mercury and was one of several factors that were found to be important (Pollman 2014). Modeling that used REMAP data found that sulfate was one of several factors that influenced mercury concentration in mosquitofish (Kalla et al. 2019, 2021). In an Everglades STA that is managed to remove phosphorus, inflow sulfate along with chloride had a significant correlation with mosquitofish mercury, suggesting that sulfate input may be a factor influencing mercury (Feng et al. 2014). Inflow sulfate, chloride, DOC, and dissolved oxygen were factors related to outflow methylmercury and total mercury (Zheng et al. 2013). Sulfide reacts with dissolved organic matter to form organic sulfur, which impacts mercury methylation and subsequent bioconcentration (Poulin et al. 2017). Modeling has been conducted to predict changes in mosquitofish mercury that would result from potential changes in sulfate export from the EAA. Reductions in excess sulfate were projected to result in, depending on location, either increases or decreases in mosquitofish mercury, with the overall shifts in mosquitofish mercury expected to be small, regardless of the magnitude of reduction in sulfate (Pollman 2012).

Whether to manage, mitigate or control sulfate because of concern about impacts to the Everglades has been debated since the 1990s. Many scientists state that it is clear sulfate contributes to mercury methylation and although high and low fish mercury are found across the spectrum of surface water sulfate concentrations, peak fish mercury occurs from about 1 to 12 or 20 mg/L sulfate, and decreasing sulfate loading to background sulfate, or <1 mg/L, would reduce methylmercury risk (Gabriel et al. 2014a, 2014b; Orem et al. 2011, 2019, 2020; Corrales et al. 2011; Pollman and Axelrad 2014, Rumbold 2019a). Other scientists argue that: a) sulfate is one of many factors that can influence mercury accumulation in gamefish such as largemouth bass; b) multiple water quality factors such as pH, specific conductivity and alkalinity also may be factors; c) there is not enough quantitative information to justify sulfur management strategies (Julian and Gu 2014, Julian et al. 2015); d) the mercury-related end products of these complexities must be predictable and quantified before an effective control or management strategy can be considered; and e) it is uncertain that reduction of sulfur inputs can reduce mercury methylation or shift methylation hot spots in the Everglades landscape or on a regional scale (Julian et al. 2016b).



Carbon

Carbon is present in all plants and animals. Organic matter refers to the carbon-based compounds found in terrestrial and aquatic environments, and it comes from the remains of plants and animals. Dissolved Organic Matter (DOM) in Everglades water plays a role in many biogeochemical and ecological processes, such as light adsorption, precipitation of minerals, and transport and reactivity of metals such as mercury. Factors that control DOM include peat drainage and oxidation, water movement and management, marsh drydown and re-wetting, and microbial and geochemical processes. DOM sources include peat, vegetation, periphyton, and detritus. A portion of DOM is dissolved organic carbon (DOC), the form that is most commonly measured (Aiken et al. 2011, Graham 2019). One of the reasons that carbon is abundant in the Everglades is because of the extensive peat soils that are as much as 90% organic matter (Figures 52, 56).

During 1993 to 1996, REMAP documented spatial gradients in surface water organic carbon in canals and in the marsh, with the highest concentrations (40-69 mg/L) observed in canals within the EAA (Figure 45, Scheidt et al. 2000). An examination of the DOM characteristics of 2005 wet season REMAP samples indicates that the origin of this carbon is the peat soils of the EAA, with export in stormwater in canals due to flood control pumping and subsequent transport into the Everglades marsh (Yamashita et al. 2010). During 1974, when water from the EAA was backpumped into Lake Okeechobee, surface water Total Organic Carbon (TOC) was about 90-106 mg/L in canals within the EAA, with a decreasing gradient with distance into the lake such that TOC decreased to about 20-50 mg/L toward the interior (Brezonik and Federico 1975).

During 2014, TOC and DOC (DOC, 0.45 μ m filter) were measured in REMAP surface water samples. Essentially all of the carbon was in the dissolved form, with the average ratio = 1.00 for DOC/TOC (n=116). During 2014, as in 2005, REMAP data show that DOC in the Everglades exhibited a spatial gradient with the highest concentrations in WCA2 and the Refuge at locations near the EAA (Figures 46 and 47). The lowest



Figure 45. Surface water samples collected during canal sampling in the 1990s. Samples with more color were collected at locations within or near the EAA, and had higher carbon content.

DOC concentrations of 11 mg/L or less were all found in the Park in areas with marl soils of low organic content (about 20%, Figures 56 and 57). These spatial gradients throughout the Everglades are consistent with those reported by other investigators (Aiken et al. 2011, Julian et al. 2017b). DOC in WCA2 was lower during the 2014 wet season sampling (median = 25.0 mg/L) compared to 2005 (median = 30.5 mg/L). DOC and TOC concentrations tend to be higher during the dry season (Figure 47) (Scheidt and Kalla 2007; Ding et al. 2014).

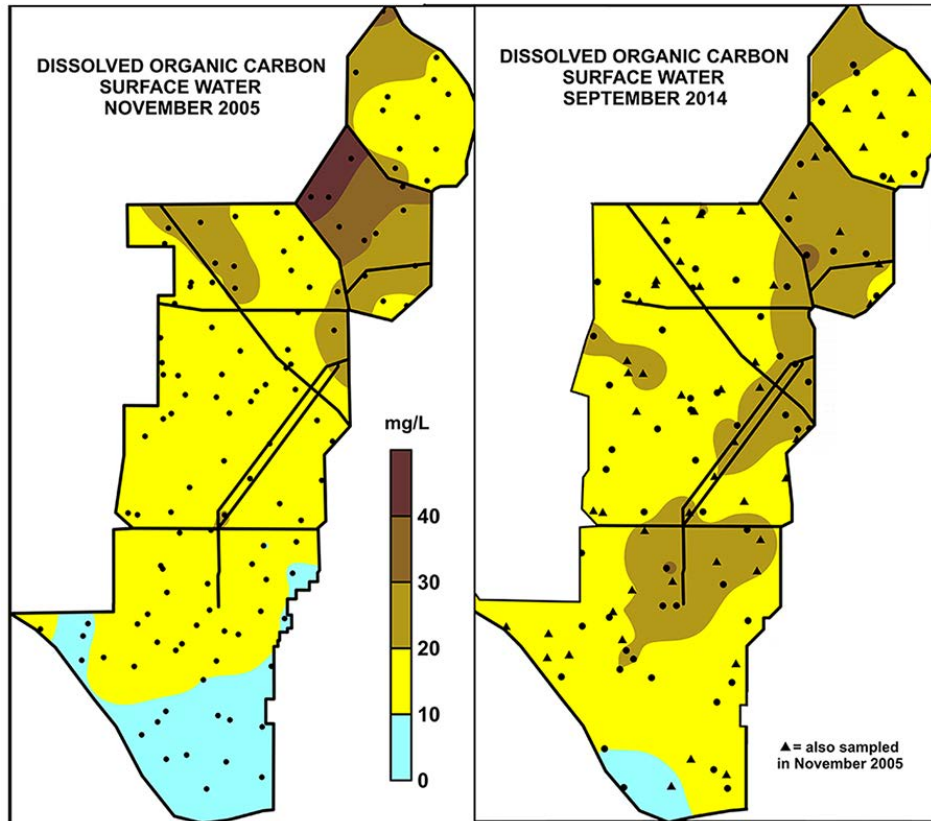
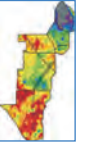


Figure 46. Surface water dissolved organic carbon (mg/L) during November 2005 (left) and September 2014 (right).

Carbon also is of interest because it plays a complicated role in mercury cycling (Graham 2019). DOM binds mercury, affects mercury solubility, and can influence the availability of mercury to microbes that methylate mercury. Areas strongly influenced by EAA stormwater have higher DOM concentrations and these areas have been reported to be more reactive with mercury than more pristine areas of the Everglades (Aiken et al. 2006). For STA2, from 2000-2011 an association was found between several water quality parameters including DOC at the STA inflow, and total mercury and methyl mercury at the STA outflow (Zheng et al. 2013). Using 2005 REMAP data, DOC was found to be associated with distribution of total and methyl mercury throughout the Everglades (Liu et al. 2009). A significant negative association was found between DOC and the mercury biomagnification factor between water and mosquitofish (Liu et al. 2008b). In the Everglades, DOM has been shown to enhance mercury methylation under low sulfide conditions (Graham et al. 2013). REMAP data from 1995-2005 were used to explore the relationship between mercury in prey fish (mosquitofish) and many biogeochemical analytes by using structural equation modeling. The modelling

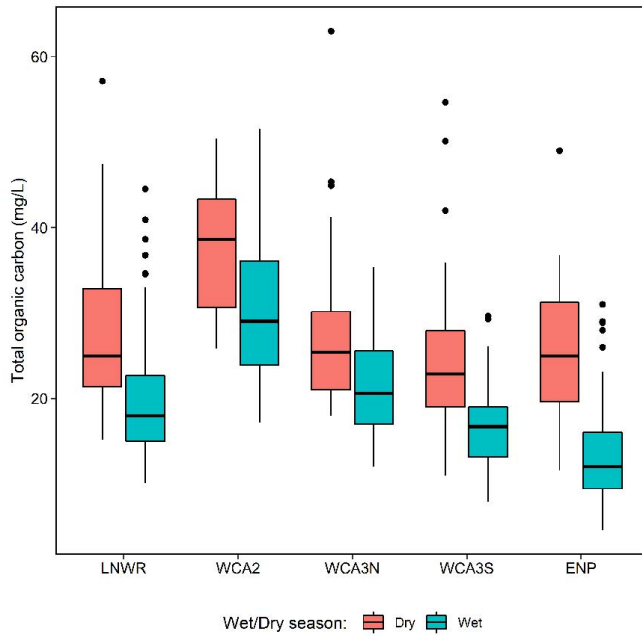
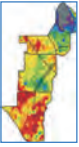
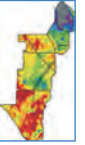


Figure 47. Wet and dry season surface water total organic carbon (mg/L) by subarea in the marsh during all REMAP sampling events.

indicated that DOC had a significant negative direct effect on mosquitofish mercury, yet DOC also had a direct positive significant effect on methylmercury in surface water and in periphyton, each of which had a direct positive significant effect on mosquitofish mercury (Pollman 2014). In contrast, during the November 2005 REMAP sampling, DOC had a significant negative association with mercury biomagnification factor (Scheidt and Kalla 2007).

From 1994 to 1999, STA1W exhibited no net removal of carbon, and about 93% of the surface water TOC was in the dissolved fraction (Gu et al. 2006). Water management and primary productivity processes in the marsh are important drivers controlling DOM dynamics (Yamashita et al. 2010), and water

management is a key driver of DOC flux from Shark River Slough in the Park to the coastal estuary (Regier et al. 2016). A focus of restoration is increasing the flow of water into areas of the Everglades and coasts without adversely impacting these areas with water of a lesser quality (Aiken et al. 2011, Graham 2019).



Dissolved Oxygen

The concentration of dissolved oxygen (DO) within the water column is an important indicator of water quality. Aquatic life such as fish depend on oxygen for survival. A common default minimum DO water quality criterion for surface water is 5.0 mg/L. During photosynthesis, plants use the sun's energy to convert carbon dioxide and water into oxygen and cellular material (growth). During respiration, animals and algae remove oxygen from the water and use it to produce energy, releasing carbon dioxide and water as by-products. In natural wet prairie and open water slough habitats of the Everglades, plants such as bladderwort and associated algal communities produce oxygen throughout the day during photosynthesis. During daylight, there is more photosynthesis than respiration, and DO levels increase. During night, respiration exceeds photosynthesis and DO decreases. Natural background areas of the Everglades exhibit a strong daily fluctuation in DO, and at a single location DO can range from 1 mg/L around sunrise to 9 mg/L around sunset. DO may not reach 5.0 mg/L until the afternoon.

Dense emergent aquatic vegetation such as sawgrass and cattail contribute little oxygen to the water. In contrast, open water sloughs produce a surplus of water DO, which can flow into adjacent sawgrass habitats. DO concentrations in sawgrass marsh are lower than in open water, but oxygen remains throughout the night. In contrast, phosphorus-enriched cattail areas become void of DO during the night (Belanger et al. 1989). At phosphorus-enriched locations DO may never exceed 1 mg/L (McCormick et al. 1997, McCormick and Laing 2003). WCA2A, which has the largest area of phosphorus enrichment and impact, also has the highest sulfate

concentrations and most extensive area of sulfate enrichment (Figures 40-41). DO concentrations also can be affected by elevated sulfate, in that sulfate loading increases microbial sulfate reduction in soils. This leads to reducing conditions, increased sulfide, and lower water column DO concentrations (Orem et al. 2011).

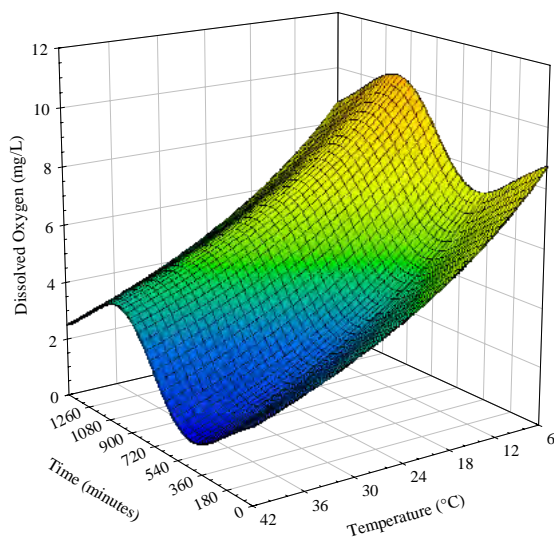


Figure 48. Daily water column dissolved oxygen (DO) at background marsh locations in the Everglades. DO peaks late in the afternoon at concentrations higher than 100% saturation, with the lowest concentrations occurring shortly after sunrise (from Weaver 2004).

Because of the natural daily variation in DO in the Everglades due to photosynthesis and respiration, in 2014 FDEP adopted a Site-Specific Alternative Criterion (SSAC) for DO to replace the 5.0 mg/L minimum requirement. Data from marsh reference sites with low TP and away from canals and groundwater influence were used to define the natural background levels and variation in DO (Figure 48, Weaver 2004). DO concentration varies naturally not only with time, but also with water temperature; as water temperature increases, the water is able to

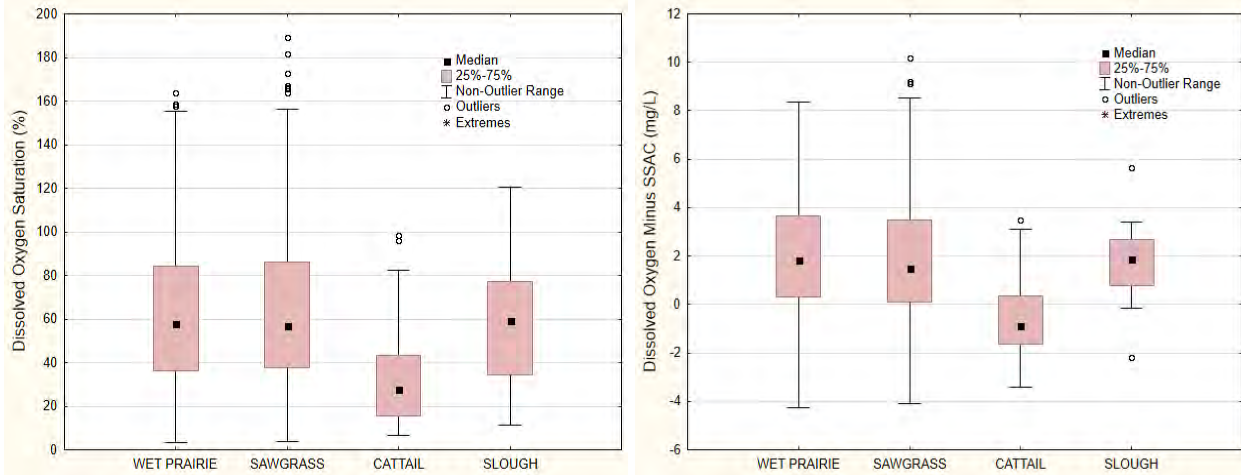
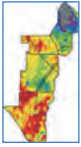
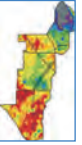


Figure 49. REMAP water column dissolved oxygen (DO) percent saturation by habitat (left), and DO concentration minus the SSAC by habitat (right).

hold less oxygen (lower saturation capacity). The DO concentration expected for a sampling event at a station is calculated from the water temperature and sampling time. The annual SSAC for the station is assessed based on comparing the annual average measured DO concentration and the average of the corresponding DO SSAC limits. In 2014 the annual minimum DO concentration required by the SSAC varied from about 1.0 mg/L to 4.0 mg/L depending upon location (Julian 2016c). As expected, phosphorus-impacted marsh sites had lower DO concentrations and they usually did not meet the SSAC (Julian et al. 2016a).

REMAP DO data are shown in Figure 49 by habitat at 833 marsh locations sampled from 1995 to 2014. DO concentration ranged from 0.3-13.6 mg/L, and from 3.5-189% saturation. Cattail had the lowest DO percent saturation, and was the only habitat that never exceeded 100% (Figure 49, left). Because REMAP data have only single measurements at a location, it is not appropriate to apply the DO SSAC to REMAP data for regulatory purposes. However, for informational purposes only, the expected DO concentration (SSAC) for the particular temperature and time that DO was measured was subtracted from the observed DO concentration (Figure 49, right). Once again, cattail was the habitat with the lowest DO concentration, and this difference was very highly significant ($F = 15.52, p < .000001$). DO in cattail was lower than the SSAC for most of the data.



pH

The pH of water or soil can influence many water quality and chemical processes. The pH is defined as the logarithm (base 10) of the reciprocal of hydrogen ion activity or concentration. The pH scale ranges from 0 to 14, with pure water having a pH of 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 natural waters is usually between 6.0 and 8.5 (Hem 1985).

Surface water pH and soil pH varied spatially during September 2014, with the lowest values found in the Refuge (Figures 50-51). Rainwater in the Everglades had a precipitation-weighted mean pH of 5.1 for 2014 (NADP 2014a). The soft (low ionic content) water of the 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 (high ionic content) waters of the Park have high buffering capacity (annual median alkalinities of about 200 mg as calcium carbonate per liter) (Weaver et al. 2007). Its low pH and soft water conditions make the Refuge vulnerable to mineral enrichment from groundwater or surface water (McCormick et al 2011).

For 2014, the median surface water pH by subarea was 6.11 for the Refuge, 7.23 for WCA3, 7.46 for WCA2 and 7.52 for the Park. Photosynthesis by aquatic organisms removes carbon dioxide from the water column during daylight hours, resulting in an increase in surface water pH (Hem 1985, Gleason and Spackman 1974). For example, in a natural wet prairie marsh in the Park, dominated by spikerush and bladderwort

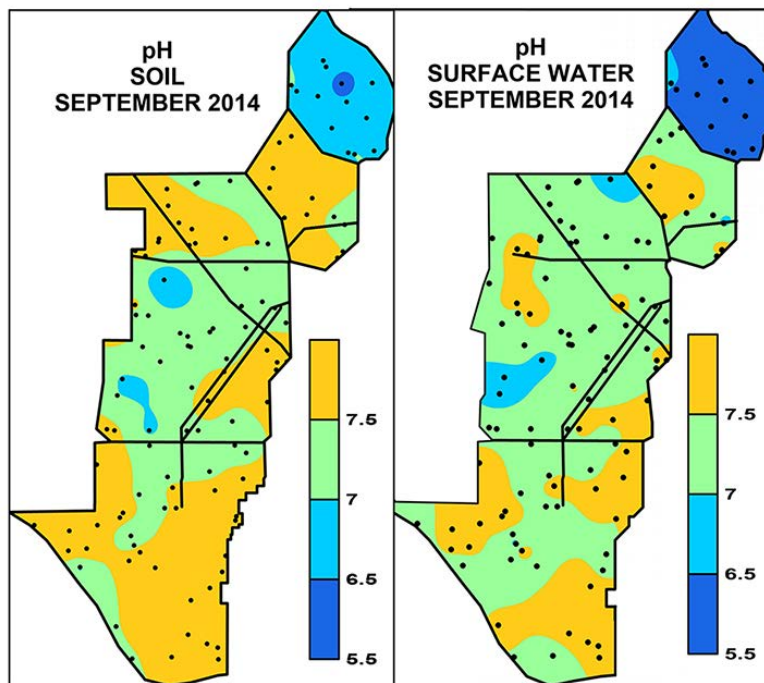
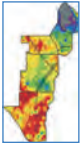


Figure 50. Soil pH (Standard Units) (left) and in-situ surface water pH (right) during September 2014.



plants and an extensive calcareous periphyton mat, the pH at a single location fluctuated over 24 hours from 7.1 at midnight to 8.5 late in the afternoon while the corresponding dissolved oxygen (DO) went from about 1.0 mg/L to 10.0 mg/L (Scheidt et al. 1985). The REMAP pH values >8 all occurred in the Park after 1400 hours. Given that the September 2014 REMAP measurements of in-situ water pH occurred between 0830 and 1730 hours, and that REMAP sampling took place from south to north over a 17-day period, the observed spatial pattern in pH cannot simply be explained by diurnal fluctuations.

Florida's water quality criterion for pH generally requires that pH shall be between 6.0 and 8.5 and shall not vary more than one unit above or below natural background (Chapter 62-302.530(52)(c) F. A. C.). From 1995 to 2014, REMAP had only 17 of 951 (2%) pH measurements that were less than 6.0, all of which were in the interior of the Refuge. Florida reports pH values <6.0 within the Refuge at a similar frequency. These excursions below the criterion are viewed as a consequence of the Refuge's naturally low alkalinity and are not of ecological concern (Julian et al. 2016a).

The lowest soil pH (median = 6.72) was within the Refuge interior, which has highly organic peat soils. The highest soil pH (median = 7.74) generally occurred within the mineral enriched soils in WCA2A, and in the Park's marl soils, which contain more calcium than peat soils. The marl soil found throughout much of the Park (Figures 56-57) contributes to buffering capacity and results in these higher pH values. Soil calcium, which contributes to higher soil pH, is five times higher in the soils within the Park's eastern marl prairies (227 g/kg) than in the peat soils of Shark River Slough (54 g/kg) (Osborne et al. 2011b).

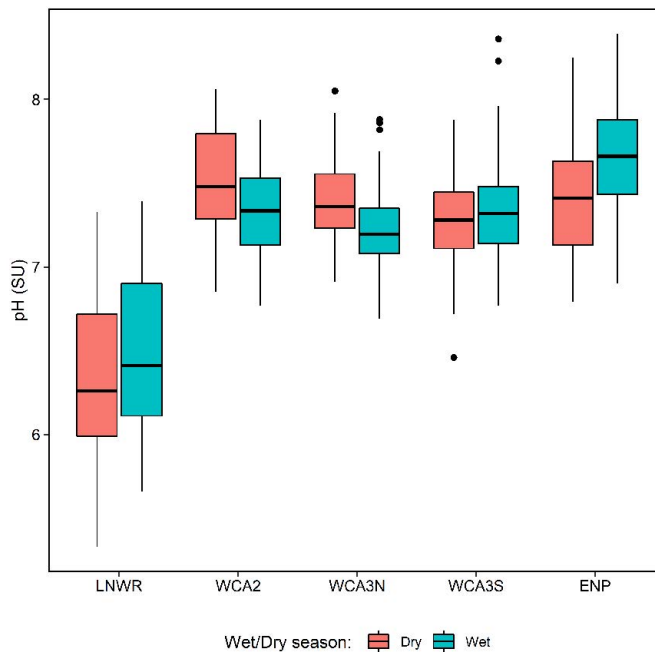
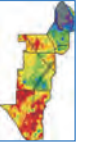


Figure 51. Wet and dry season marsh surface water pH (Standard Units) by subarea during all REMAP sampling events.



SOILS and SOIL SUBSIDENCE

Soil is a defining characteristic of an ecosystem, and soil preservation is important for ecosystem protection and restoration (Scheidt and Kalla 2007, Nungesser et al. 2014, Orem et al. 2014b). 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 in the Everglades and stopping soil subsidence (RECOVER 2007).

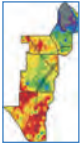
There are two major soil types in the Everglades (Figure 52). The wetland soils of the central Everglades are primarily peat formed by slowly decaying plant matter in areas that are flooded much of the year. The other major soil type is calcitic mud or marl commonly found in the shallower peripheral marshes of the Park that have shorter periods of surface water inundation. Marl is found in association with thick, calcitic algal mats (periphyton) (Figure 58, Eastern Marl Marsh), which precipitate calcium carbonate from the water column in these hard water areas (Gleason and Stone 1993).



Figure 52. Everglades peat (top, organic matter 78%, WCA2A) and marl (bottom, organic matter 14%, the Park). Bottom photo also shows a benthic periphyton mat overlaying the soil core.

Historically, the Everglades contained the largest body of organic peat soils in the world, covering over 3,000 square miles and accumulating to a thickness of up to 17 feet in what would become the EAA (Stephens and Johnson 1951). The origin and perpetuation of peat and marl soils are dependent upon water depth, the duration of surface water inundation, and the resulting wetland vegetative communities. Shortened 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 in turn may cause further changes in soil type and thickness as this different plant community eventually decomposes and forms altered soil. Some soil cores collected by REMAP have alternating peat and marl layers within the 0-10 cm profile.

Soil loss within the Everglades is largely due to water management practices during the last 100 years. The major canals draining the EAA were completed by 1917 and extend southeast through the Everglades to the Atlantic Ocean. 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, Everglades surface water depths, flow, and inundation periods had been greatly altered (Light and Dineen 1994).

Peat soils are subject to subsidence and loss of surface elevation when drained. Oxidation, burning and compaction are considered the dominant subsidence forces. An inch of Everglades peat that takes a century to form can be lost within a few years, or within hours if dry soils are subjected to fire. In the early 1900s, 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 drainage canals were cut from Lake Okeechobee through the EAA to the coast (Stephens 1956). Subsequent subsidence within the EAA and efforts to control it on agricultural lands are well documented (Shih et al. 1998, Ingebritsen et al. 1999, Snyder 2005). In 1912, much of the EAA had soils thicker than 10 feet, or 120 inches (Stephens and Johnson 1951, Stephens 1956). By 1988, only 18% 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 (Cox et al. 1988). By 2050, under current agricultural practices, up to 93% of the EAA is projected to have soils less than 36 inches thick, with 82% less than 20 inches thick and 53% less than 8 inches thick. The decrease in soil volume from 1988 to 2050 is projected to be 57% or $1.2 \times 10^9 \text{ m}^3$ (Snyder 2005). Geospatial techniques have been used to estimate that during the 1900s about two-thirds of the peat volume within the EAA ($4.5\text{--}4.9 \times 10^9 \text{ m}^3$) was lost due to subsidence (Aich et al. 2013).

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 most of the year, is now an average of 2 meters lower than it was in 1910 due to subsidence (Aich et al. 2013). Frequent wet season rain events necessitate recurring pumping in order to maintain the water table below the ground surface, which continues to subside further. Each flood control pumping event has the potential to leach and export soil constituents, such as phosphorus, nitrogen, sulfur and carbon, in the water pumped southward to the Everglades. Agricultural Best Management Practices (BMPs) are directed at phosphorus removal (Iudicello et al. 2016). The STAs are more effective at removing phosphorus than nitrogen, sulfur or carbon. Projections that one-half of the EAA may have less than 8 inches of soil by 2050 bring into question the viability of agriculture with current practices (Snyder 2005). Conversion from agriculture to residential land use could result in the need to export greater volumes of stormwater and its constituents to the Everglades, if residential land use requires that the water table be maintained at even lower levels to provide flood control. The rate of soil subsidence slowed from 1.12 inches per year between 1924 and 1967 to 0.55 inches per year between 1967 and 2009. Implementation of BMPs since the 1990s has led to more water storage on EAA fields, which has slowed subsidence (Wright and Snyder 2016). Raising water levels and increasing biomass also would slow subsidence (Rodriguez et al. 2020), as would using agricultural lands for water storage (Ouellette et al. 2018).

During the 1995-96, 1999, 2005, and 2014 REMAP sampling events, a metal probe was inserted to the point of refusal to measure soil thickness (0.00 to 12.00 ± 0.05 feet) at 976 locations (Figure 53). REMAP is the only source of directly measured soil thickness data throughout the Everglades post-1940s. Comparisons

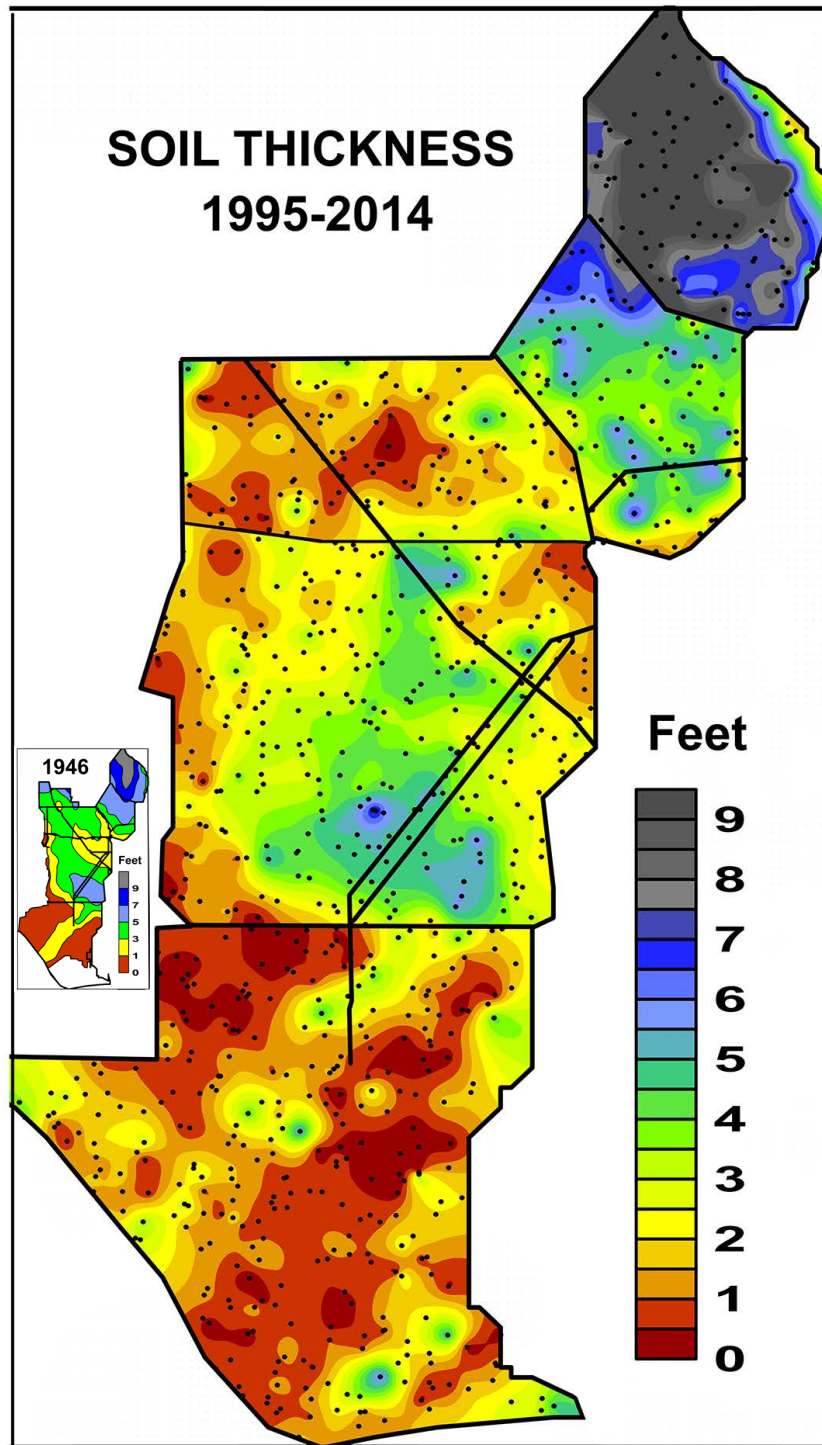
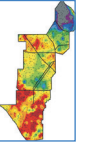
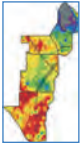


Figure 53. Soil thickness at 976 locations measured by REMAP for all sampling events from 1995 to 2014. The inset shows soil thickness as reported in 1946 (Davis).



From the 1940s to the 1990s, over one-half of the soil was lost from drier portions of the Everglades. Longer periods of surface water inundation would help to maintain marsh soils and the plant communities and wildlife habitat of these wetlands.

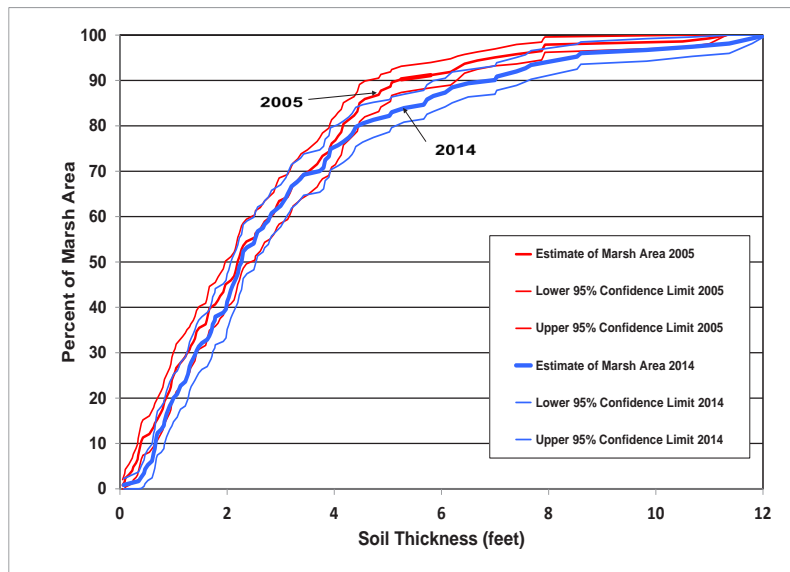


Figure 54. Soil thickness (feet) estimates of marsh area for 2005 and 2014. Soil thickness was not different (Wald F test, $p=0.68$).

of soil thicknesses measured by REMAP in 1995-96 to those reported by Davis in 1946 indicate that the drier short hydroperiod portions of the Everglades, such as WCA3 north of I-75 (Figure 21), lost 39% to 65% (2.0 to $6.0 \times 10^8 \text{ m}^3$) of their soil. Soil thicknesses of 3 to 5 feet in the 1940s had diminished to only 1 to 3 feet by 1995-96, with less than 1 foot remaining in some areas. WCA3B 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 levees that surround the WCAs in the 1950s and 1960s. From the 1940s to 1990s, the entire Everglades Protection Area lost up to 28% of its soil volume due to oxidation and subsidence (Scheidt et al. 2000).

Comparison of REMAP data from 2014 to 2005 do not indicate any further subsidence of soils landscape-wide (Figure 54, Wald F test $p=0.68$). Soil thickness data from 1995-2014 were combined and the study area was divided into 10 subareas (Figure 55). The WCAs were divided into five subareas: the Refuge, WCA2, WCA3A north of I-75, WCA3A south of I-75, and WCA3B. The Park also was divided into five subareas: Shark River Slough, Northeast Shark Slough, Eastern Marl Marsh, Taylor Slough, and Ochopee Marl Marsh. The deepest soils are the peat deposits within the Refuge, with a median soil thickness of 8.6 feet (Table 4, Figures 53 and 57). The maximum soil thickness measurable with the probes was 12.00 feet, so deeper peat in the Refuge is possible. The deepest median soil thicknesses for the other portions of the Everglades were 4.2 feet in WCA2 and about 3 feet in WCA3A south of I-75 and WCA3B, areas which typically stay inundated year-round. Median soil thickness in Shark River Slough was 1.5 feet, and the marl marshes in the Park that dry out more frequently than other parts of the Everglades had median soil thicknesses of less than 1.0 feet. The overall median soil thickness for the Everglades was 2.3 feet.

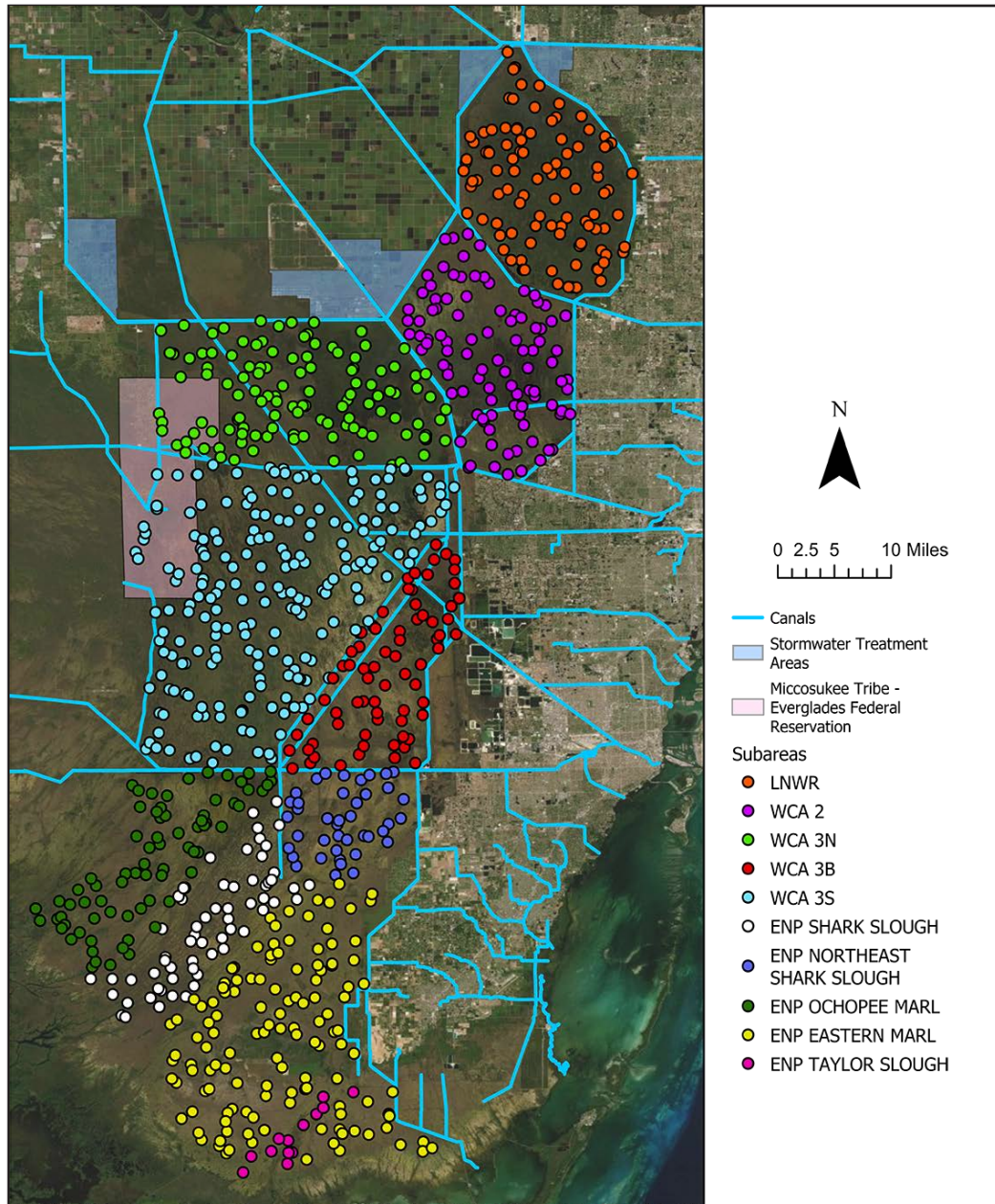
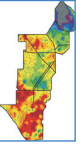
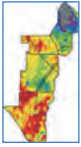


Figure 55. Ten subareas used for soil thickness and volume calculations.

Soil volume in the freshwater Everglades was calculated by subarea as the area times the median soil thickness. Summing the subareas results in an overall soil volume of $4.7 \times 10^9 \text{ m}^3$ (Table 4). Other investigators used historical data sets to calculate soil volume by subtracting the current ground surface elevation from the bedrock surface elevation. They also obtained a soil volume estimate of $4.7 \times 10^9 \text{ m}^3$ although some of



	Area (km ²)	Count	Median Soil Thickness (feet)	Median Soil Thickness (m)	Volume (m ³)
LNWR	567.0	104	8.57	2.61	1.49 x 10 ⁹
WCA2	539.0	104	4.15	1.26	0.69 x 10 ⁹
WCA3AN	715.8	129	1.60	0.49	0.35 x 10 ⁹
WCA3AS	1288.0	224	2.90	0.88	1.14 x 10 ⁹
WCA3B	401.4	78	3.25	0.99	0.40 x 10 ⁹
ENP Ochopee Marl Marsh (OMM)	437.6	79	0.83	0.25	0.11 x 10 ⁹
ENP Shark River Slough (SRS)	357.6	67	1.50	0.46	0.16 x 10 ⁹
ENP Northeast Shark Slough (NESS)	251.1	44	1.64	0.50	0.12 x 10 ⁹
ENP Eastern Marl Marsh (EMM)	830.5	134	0.70	0.21	0.18 x 10 ⁹
ENP Taylor Slough (TS)	59.1	13	3.00	0.91	0.05 x 10 ⁹
TOTAL	5447.1	976	2.30	0.70	4.69 x 10 ⁹

Table 4. Soil thickness and volume by 10 subareas, REMAP data 1995 to 2014.

the subarea volumes differed. Today the Everglades covers about one-half of the area than it did historically, but less than one-quarter of the peat remains. One-half of the carbon in the peat soils has been lost (Hohner and Dreschel 2015, Dreschel et al. 2017). This peat loss is a concern for Everglades restoration (Nungesser et al. 2014). Managing water is essential to preventing overdrainage and further loss of peat soils.

The soil organic matter content observed by REMAP from 1995 to 2014 ranged from 1% to 100% (Figures 56 to 57), 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%. WCA2A and WCA3 south of I-75 also had soils exceeding 75% organic matter. These highly organic zones coincide with the longer hydroperiod portions of the Everglades. The area of maximum soil loss within WCA3A north of I-75 had a median soil organic matter content of 75%, the lowest in the Water Conservation Areas. The peat soils in the Shark River Slough trough of the Park had a median organic matter of 78%, in contrast to the marl soils of the Park which had a median of only 27%.

Soil bulk density, the mass of dry soil per unit of bulk volume, ranged from 0.04 to 0.90 g/cc (Figures 56 to 57). 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 WCA3A north of I-75 was 0.17 g/cc, the highest in the WCAs. Within the WCAs, this portion of northern WCA3A had the lowest organic matter content, the highest bulk density, and the greatest soil loss. All of these observations are suggestive of formerly deeper peat soils of the 1940s being subjected to drier conditions due to water management changes. Surface water inundation has been decreased, and consequently soils have subsided and become less organic due to increased biochemical oxidation and more frequent wildfires.

A focus of Everglades restoration and the Central Everglades Planning Project (CEPP) is restoring more natural water flow, depth, and duration into and within WCA3 and the Park by: increasing storage,

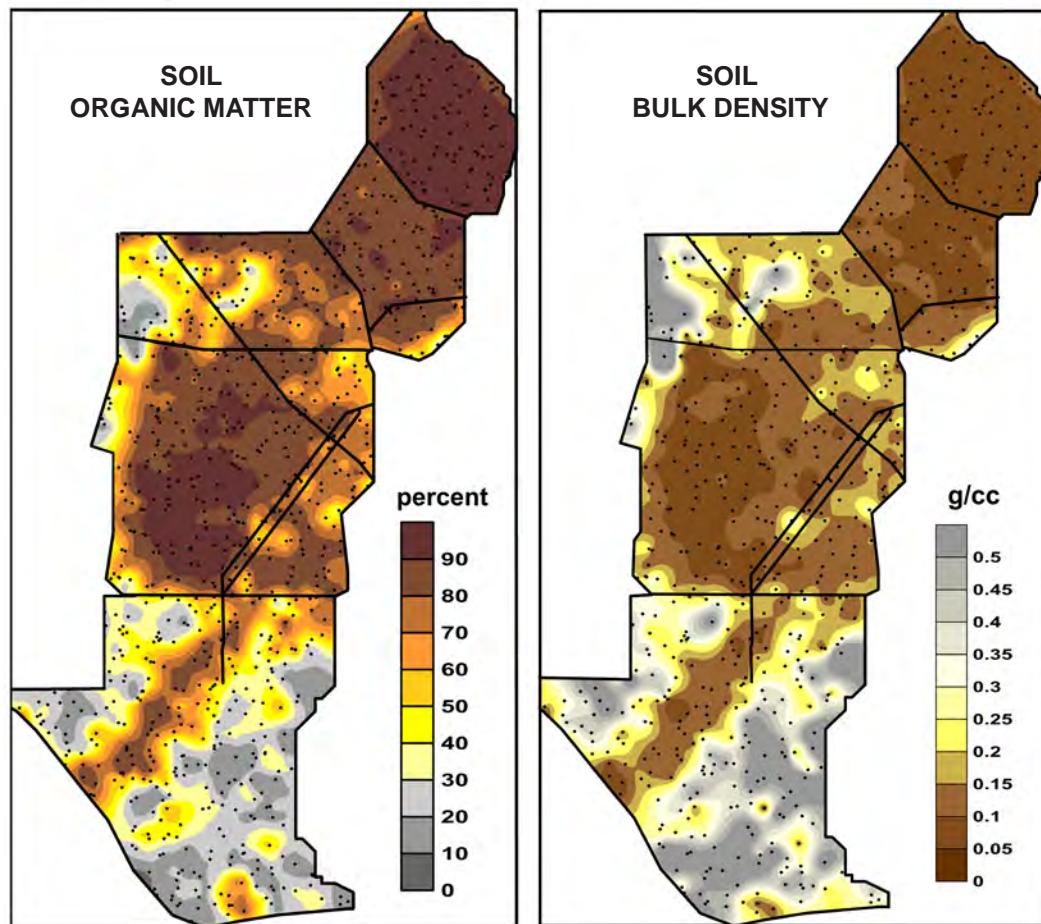
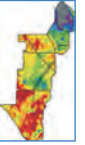


Figure 56. Soil percent organic matter (left) and bulk density (g/cc) (right), 0-10 cm profile. Soils in the Park with organic matter < 30% typically are marl, and organic matter > 50% indicates peat soils.

treatment and conveyance of water south of Lake Okeechobee; removing canals and levees within the central Everglades; and retaining water within the Park while protecting urban and agricultural areas to the east from flooding (USACE 2014). It is expected that returning the water flows of the central Everglades to a more natural state will decrease peat subsidence, increase soil accretion and return the central Everglades to a net carbon sink (Richardson et al. 2014). Hydroperiod and nutrient availability drive plant litter decomposition and are important to peat formation and accumulation (Pisani et al. 2018). It is also essential to reduce nutrient inputs if natural peat accumulation is to be restored (Sklar et al. 2005a, Sklar et al. 2010, Osborne et al. 2017). Further decreases in water depth and inundation periods would alter the Everglades ecosystem through drought, peat loss and carbon emissions, wildfires, loss of the unique ridge and slough patterns, shifts in plant and animal communities, and spread of exotic species. Adaptive restoration planning incorporates climatic and environmental uncertainties into long-term ecosystem restoration plans, structural design, and management (Nungesser et al. 2014, Flower et al. 2019).

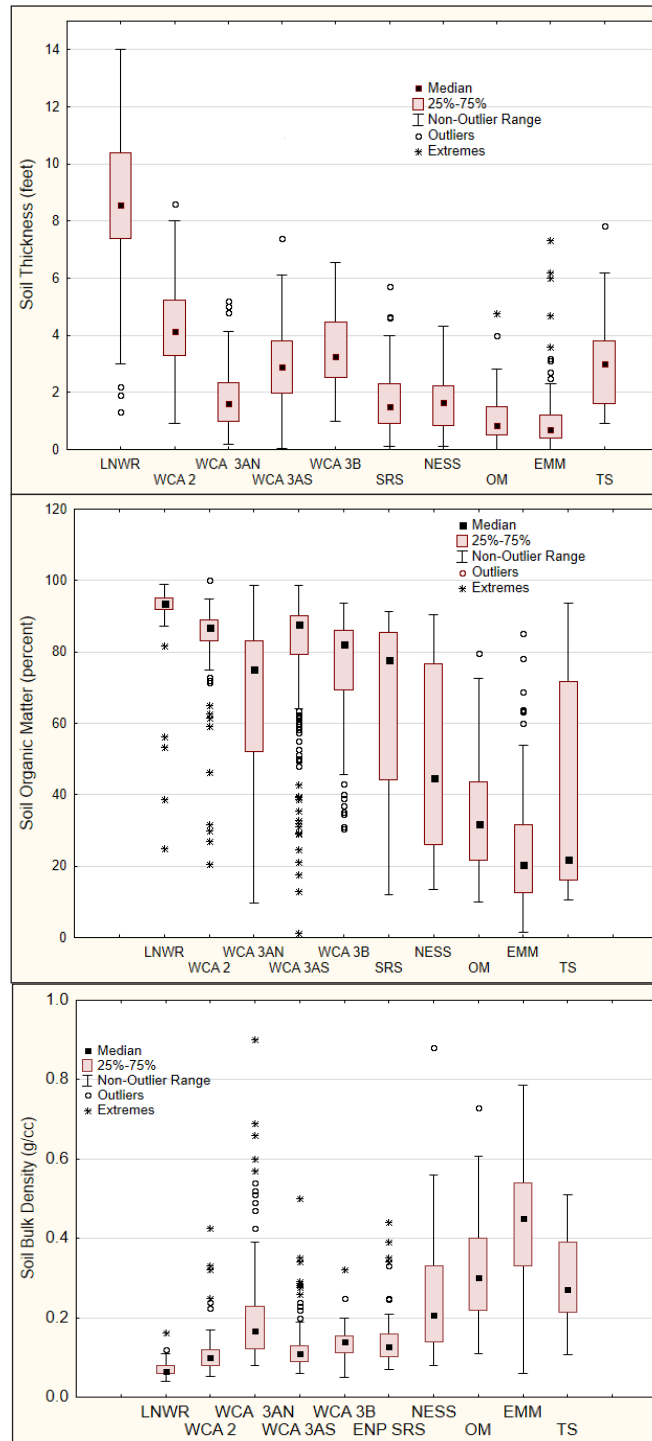
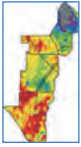
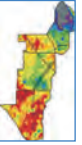
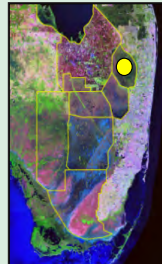


Figure 57. Soil thickness (feet, top), percent organic matter (middle) and bulk density (g/cc, bottom) by 10 subareas.



Loxahatchee National Wildlife Refuge



Peat soil
 Soil Thickness > 8.6 ft (median, n=104)
 Bulk density = 0.06 g/cc
 Organic matter = 94%
 Water depth (1994-2014)* = 1.0 ft*
 Days Dry = 2%*

* water level gage 1-7, data from EDEN



WCA 3A South



Peat soil
 Soil Thickness = 2.9 ft (median, n=224)
 Bulk density = 0.11 g/cc
 Organic matter = 88%
 Water depth (1994-2014)* = 2.2 ft
 Days Dry = 0%*

* water level gage 3-65, data from EDEN

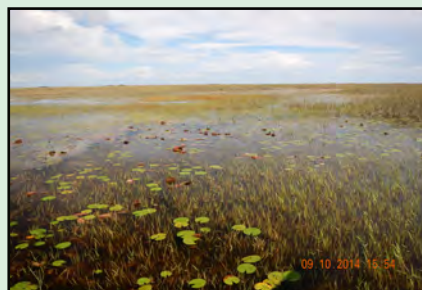
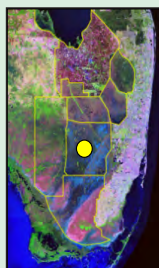
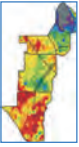


Figure 58. Contrasting soil and vegetation characteristics of selected locations in the Refuge (top), WCA3A south (bottom) and the Eastern Marl Marsh in the Park (next page).



Eastern Marl Marsh - Rocky Glades

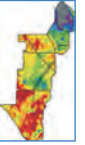


Marl soil
Soil Thickness = 0.7 ft (median, n=134)
Bulk density = 0.45 g/cc
Organic matter = 21%
Water depth (1994-2014)* = 0.14 ft
Days dry* = 42%

* water level gage NP206, data from EDEN



Figure 59. Interstate 75 at the eastern edge of the Everglades looking west. Northern WCA3A is to the right. Shortened periods of surface water inundation in northern WCA3A have led to soil loss since the 1940s.



MACROPHYTES and PERIPHYTON



Figure 60. Mosaic of tree islands, sawgrass marsh and wet prairies within Shark River 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 such as tree islands, sloughs, wet prairies and sawgrass marshes (Figures 1, 2, 60). Factors driving vegetation community composition include hydroperiod, water depth, water velocity, nutrients, invasive plant species that are not native, disease, and disturbances such as fire, frosts, and hurricanes. Wet prairies and open water sloughs without dense plants growing out of the water (emergent macrophytes) serve as preferred habitats for foraging wading birds (Bancroft et al. 1992). These areas are the marsh habitats with the greatest diversity of native flora and fauna (Gunderson and Loftus 1994). Classified vegetation maps were produced for 1 km² areas centered on each REMAP station during 1999 (Stober et al. 2001b, Welch and Madden 2000) and 2005 (Richards and Philippi 2005). In addition, during 1999 and 2005 plant species frequencies were determined along transects (Stober et al. 2001b, Richards and Philippi 2005). In 2005 the presence and distribution of non-native or invasive plant species were determined using several methods (Richards and Philippi 2005).

During the September 2014 REMAP event there were several efforts to document vegetation. WorldView-2 satellite imagery of a 1 km² area centered on 65 REMAP sampling stations was used to create classified vegetation community maps. Vegetation mapping provides a landscape context for REMAP biogeochemical and biotic information. Standing stocks of carbon, nitrogen and phosphorus in sawgrass, water, soil, floc, and periphyton were estimated (Richards et al. 2017). Digital photographs document plant communities during September 2014 at all 118 sampling locations: a ground view of the area sampled to the left of the helicopter,

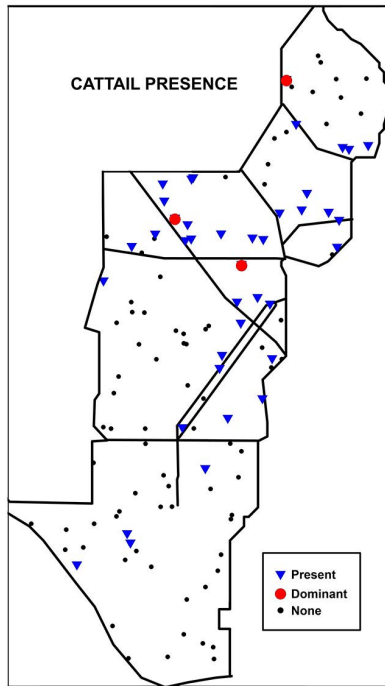
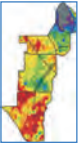


Figure 61. Cattail presence during September 2014.

nine panoramic photos at 45-degree increments, each of the three soil cores, and an aerial view at 100-200 feet. For each station, photodocumentation, classified vegetation maps, and biogeochemical data from 2014 and 2005 are available at: <http://digir.fiu.edu/gmaps/EverREMAP.php>. Field crews also recorded the dominant plant community at each sample point based on visual observation. In addition, vegetation was sampled at a subset of stations for chemical analyses: sawgrass leaf clippings at 60 stations for carbon, nitrogen, and phosphorus; and whole sawgrass plants at 27 stations for total mercury and methylmercury.

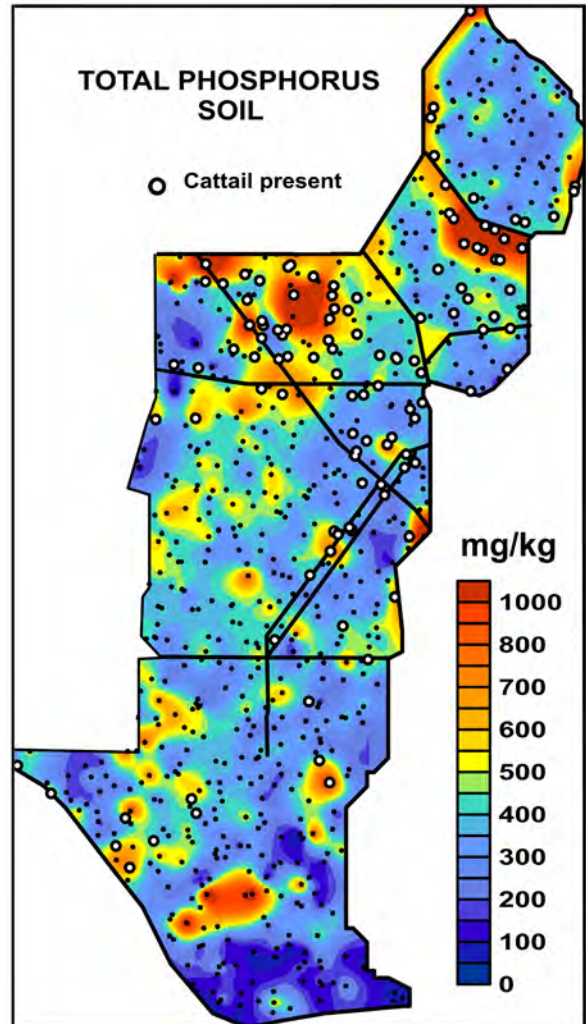
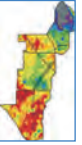


Figure 62. Soil total phosphorus (mg/kg) and cattail presence based on REMAP data 1995 to 2014.

Cattail is a native species that can respond to phosphorus enrichment and replace sawgrass, water lily in sloughs, and wet prairie plants such as spikerush and bladderwort. Cattail expansion was one of the first visual consequences of P enrichment observed during the 1970s (Davis 1994). The rate of cattail expansion in WCA2 from 2003 to 2011 was only 20% of the rate of expansion from 1996 to 2003 (Zweig and Newman 2015). Conversion of wet prairies with open water to dense cattail constitutes a loss of the preferred foraging habitat for wading birds (Turner et al. 1999). There is an association between cattail presence and elevated soil phosphorus or proximity to canals (Figures 61-62, Scheidt and Kalla 2007).



Low phosphorus conditions are required for natural Everglades periphyton and plant communities to be maintained.

Periphyton

Periphyton is a complex mixture of algae, bacteria, microbes, and detritus that is attached to submerged surfaces. Periphyton can be found in abundance throughout the natural Everglades ecosystem, and includes: loose, flocculent aggregations in the soft-water Refuge; thick, calcareous mats in the central Everglades sloughs; and benthic mats in the Park’s marl prairies (Gaiser et al. 2011). Well-developed, attached or floating calcareous periphyton mats are a conspicuous and defining characteristic of the hard-water Everglades, particularly in wet prairies and deeper slough areas (Figures 63-64). The natural periphyton mats across mineral-rich portions of the Everglades (see section on specific conductance) are dominated by calcium-precipitating (calcareous) cyanobacteria and have a high calcium carbonate content, while those in the soft-water Refuge are largely organic (non-calcareous) (McCormick et al. 2011). These assemblages of 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 food web (McCormick et al. 1999).

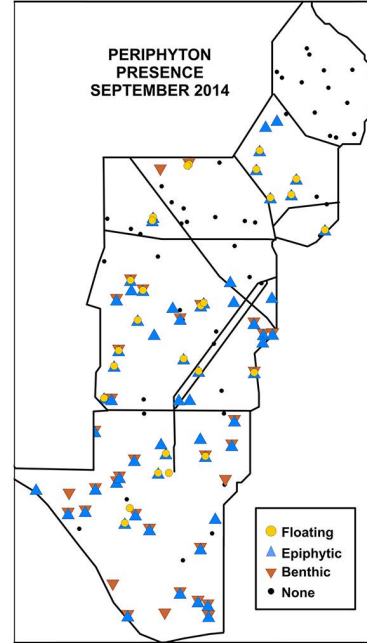
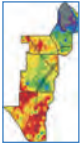


Figure 63. Presence of floating, benthic, and attached (epiphytic) calcitic periphyton communities during September 2014.

Hydroperiod and water depth, water ions, and phosphorus concentration all affect periphyton extent and community structure (Browder et al. 1993). 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 is a sensitive and important indicator of Everglades marsh ecosystem status (Gaiser 2009, Gaiser et al. 2004, McCormick et al. 2002, Surratt et al. 2012). In the Refuge, shifts in periphyton community



Figure 64. Types of Everglades calcitic periphyton communities sampled: epiphytic - attached to plants such as bladderwort (left) or ‘sweaters’ attached to spike rush shown on a gloved hand (middle); and benthic at the soil surface within a 0.5 meter wide quadrat (right).



composition and function provide an especially sensitive indicator of mineral enrichment (McCormick et al. 2011). Monitoring and species-based approaches provide early warning signs of environmental change that are only later identified using traditional water quality approaches, and that have the potential to be propagated into higher trophic levels. Changes in periphyton biomass, nutrient content and composition can have cascading effects upon the Everglades food web (Gaiser et al. 2005, 2015).

During 2014 REMAP documented three types of easily-seen calcareous periphyton growth forms (Figures 63-64): periphyton floating on the surface or within the water column; epiphytic periphyton or ‘sweaters’ attached to plants; and benthic periphyton as a discrete layer at the soil surface. The most common form of periphyton was epiphytic, which was observed at 53% of the stations, followed by benthic (31%) and floating (23%). Benthic mats were most common in the marl, short-hydroperiod portions of the Park. Percent periphyton cover, which was documented within a randomly located 0.25 m² frame, ranged from 0-100%. There were no periphyton mats or sweaters sampled in the soft-water Refuge due to the loose, flocculent nature of the periphyton there and time constraints on REMAP field sampling crews. Generally, there was no periphyton observed or sampled in most of northern WCA3A, an area with shortened hydroperiod and higher risk of fire.

Floc

A conspicuous layer of flocculent matter (floc) is present at the sediment-water interface in much of the Everglades (Figures 65-66). Floc in the Everglades is believed to consist of an assembly of plant detritus, periphyton, carbonates, and other remains of aquatic organisms (Neto et al. 2006). Floc plays a role in nutrient

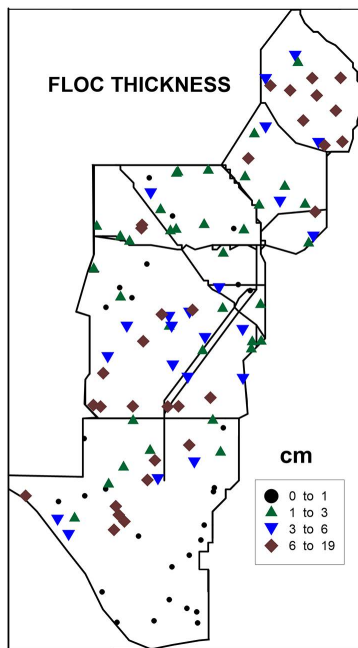


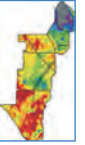
Figure 65. Floc thickness (cm) during September 2014.

and carbon cycling and resuspension. Detrital remains of plants such as bladderwort (*Utricularia* species) comprise the primary components of floc in deep sloughs in WCA3 (Troxler and Richards 2009). In 2014, REMAP floc thickness ranged from 0-19 cm, with the thicker layers generally occurring at the longer hydroperiod locations. Mass balance estimates using REMAP 2014 data show that floc contains a significant pool of carbon, nitrogen and phosphorus (Richards et al. 2017). The TP content of floc is a sensitive indicator of enrichment at marsh transects downstream of



Figure 66. Peat soil and an extensive floc layer at the surface water - soil interface.

structures discharging into the Refuge, WCA2, WCA3A within the Miccosukee Tribe's Federal Reservation, and Taylor Slough in the Park (Wright et al. 2009).



MERCURY

Mercury contamination of gamefish and wildlife in the Everglades has been a management concern and focus of research and monitoring since the 1990s. The primary sources are atmospheric. Mercury falls on the Everglades as gaseous divalent mercury (HgII). Biogeochemical processes within the Everglades marsh convert this mercury to methylmercury, a toxic form. Methylmercury accumulates (bioaccumulates) in the tissue of aquatic organisms in the Everglades. Mercury also increases in concentration (biomagnifies) the higher an animal is in the food chain, and at higher concentrations it presents a risk to wildlife and humans through fish consumption.

During the early 1970s, mercury was documented in birds and gamefish in Everglades National Park, and mercury was identified as a potential ecological concern (Ogden et al. 1974). In the late 1980s, unexpectedly high levels of mercury were found in gamefish and two dead Florida panthers in the Park (Roelke et al. 1991). The mercury sources were unknown. In order to protect human health, in 1989 Florida issued a consumption advisory either restricting or recommending no consumption of gamefish such as largemouth bass from the Everglades (FDHRS 1989) (Figure 67). Consumption advisories have remained in place throughout the Everglades since, with the current advisory recommending that women of child-bearing age and young children should not eat largemouth bass, and should limit consumption of 17 other fish species (FDOH 2020). The existence of these advisories means that the Everglades waterbody does not meet the “fishable” portion of its designated use under the Clean Water Act. 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 in that mercury accumulation through the food web has the potential to reduce the health or breeding success of wading birds (Rumbold 2005, 2019b; Rumbold et al. 2008, Spalding et al. 2000, Duvall and Barron 2000, Zabala et al. 2020) and the Florida panther (Barron et al. 2004, Rumbold 2019b).

In the early 1990s, the South Florida Mercury Science Program was established. This program was a collaborative effort by FDEP, USEPA, SFWMD, Florida Game and Freshwater Fish Commission and the USGS. The program was designed to determine: the

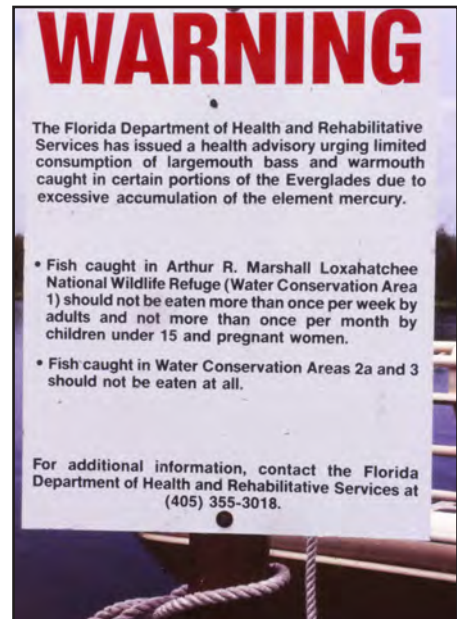
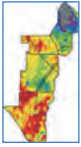


Figure 67. Young fisherman and fish consumption advisory to protect human health at the main Refuge boat ramp. Depending upon the location in the Everglades, Florida’s present advisory recommends that women of child-bearing age and young children should not eat largemouth bass, and should limit consumption of 17 other fish species (FDOH 2020).



sources of mercury; potential risks to humans and wildlife; how mercury enters the aquatic food chain and bioaccumulates; how inorganic mercury is transformed into methylmercury; how mercury cycles through air, water and soil; and what actions could be taken to decrease mercury levels in wildlife and gamefish (FDEP 1997). Potential mercury sources were: stormwater pumped into the Everglades from the Everglades Agricultural Area; release from Everglades soils into water during wet season rewetting; burning of sugarcane during harvesting; medical and municipal waste incinerators; and other sources of emissions into the atmosphere. It was determined that atmospheric deposition was by far the predominant mercury source to the Everglades, originating from both within and outside of Florida (FDEP 2013).

Florida's class III surface water criterion for total mercury is 12.0 nanograms per liter (ng/L or parts per trillion). Since 1995, including all sampling events, REMAP has sampled 851 locations within the Everglades marsh for total mercury in surface water, and only 6 samples exceeded 12.0 ng/L. All 6 samples were collected during the dry season (1990s and 2005) at shallow marsh sites (water depths from 0.1 to 0.7 feet). Biomagnification and bioaccumulation of mercury to unacceptable levels in gamefish occurs even though surface water concentrations are below the 12 ng/L criterion.

Divalent mercury in rainfall that is deposited into surface water can be converted to methylmercury (MeHg) by bacteria in the presence of sulfate and organic carbon (Orem et al. 2011, Aiken et al. 2011). Methylmercury is the form of mercury that bioaccumulates and biomagnifies in the aquatic food chain. Concentrations in largemouth bass are 10 million times higher than concentrations in surface water. There is no numeric water quality criterion for MeHg in surface water in the Everglades. Many factors affect the bioaccumulation of mercury in aquatic life, such as the length of the aquatic food chain, soil type, pH, and dissolved organic material (USEPA 2001). During the last two decades, about 30 factors have been suggested by scientists as affecting mercury bioaccumulation in the Everglades. Interrelationships among the factors are complex and may be waterbody-specific. Because of these complexities, USEPA concluded that in order to protect human health it is more appropriate to have a water quality criterion for MeHg based on fish tissue concentrations, rather than on water concentrations. The MeHg water quality criterion USEPA recommended in 2001 is a fish tissue residue criterion of less than 300 micrograms per kilogram ($\mu\text{g}/\text{kg}$, or parts per billion), or 0.3 mg/kg (USEPA 2001).

Accordingly, Florida uses fish consumption advisories based on mercury in gamefish exceeding 0.3 mg/kg to determine that a waterbody is impaired (is not meeting its designated use, i.e., is not fishable) (FDEP 2013). In 2013 Florida adopted a statewide mercury Total Maximum Daily Load (TMDL) to establish the allowable loadings and needed reductions of mercury into Florida's fresh and marine waters that would restore these waterbodies so that the human health concern associated with the elevated mercury in fish tissue impairment will be addressed. The TMDL calls for an 86% reduction in mercury sources, which arrive in Florida waters predominantly by atmospheric deposition, and are from both within and outside Florida. Over 95% of wet and dry deposition of mercury to the Everglades originates outside of Florida (FDEP 2013), and it is estimated that 85% to 95% of the mercury deposited on the Everglades is from the long-range transport of mercury from sources outside of the United States (Vijayaraghavan and Pollman 2019).

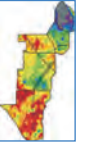


Figure 68. Mosquitofish, such as most of the fish shown here, are the most abundant fish in the Everglades and are an ideal indicator of mercury.

Previously, Florida's anthropogenic atmospheric mercury emissions were significantly reduced, from about 160,000 pounds per year in 1988 to 3,000 pounds in 2009, due to air pollution emission reductions required by the federal Clean Air Act and Florida's implementing rules (FDEP 2013).

Mosquitofish (Figure 68) are a small preyfish (maximum length 1.5 inches, $n=1841$, REMAP 2005 and 2014) that have been sampled by REMAP since the 1990s because they are an ideal indicator of mercury contamination: a) they are the most abundant fish in the Everglades and are found throughout the canals and in all marsh habitats; b) they are easily sampled; c) they are a prey fish in the food web for gamefish and wading birds, so they provide insights for both human health and ecological health; and, d) because of their lifespan of only several months and a small home range, they integrate mercury exposure over a short time frame in a discrete area. During the five REMAP wet season sampling events, mosquitofish were collected at 94% of the 532 Everglades marsh sites, including wet prairie, sawgrass and cattail habitats. Everglades mosquitofish are a secondary consumer reported to be at trophic level 2.0 to 3.0 (Loftus et al. 1998) and 4.0 to 4.5 (Williams and Trexler 2006). They consume animal prey (crustaceans, insects, arachnids), algae, detritus and plant matter (Loftus et al. 1998). USEPA has recommended a mercury concentration of 77 $\mu\text{g}/\text{kg}$ at trophic level 3 for protection of birds and mammals (USEPA 1997), while the United States Fish and Wildlife Service has recommended a level of 100 $\mu\text{g}/\text{kg}$ in prey fish in order to protect top predators such as wading birds from mercury contamination (Eisler 1987).

During 1995-96 and 2005, REMAP documented a pronounced spatial gradient in mosquitofish mercury, with the highest concentrations in remote portions of WCA3A and extending into Shark River Slough in the Park (Figure 69) (Stober et al. 1998, Stober et al. 2001b, Scheidt and Kalla 2007). These results are consistent with those for other biota indicating that the highest mercury in the Everglades occurs in the Park or WCA3 for largemouth bass and great egrets (Axelrad et al. 2007) and alligators (Rumbold et al. 2002). A risk assessment on the effects of MeHg on great egrets concluded that birds foraging in the Park have a high probability of exceeding both the daily and cumulative acceptable dose levels necessary to protect nestlings and pre-nesting females (Rumbold et al. 2008). A regional-scale ecological risk assessment and synthesis concluded that mercury remains a risk to a variety of birds and mammals in certain South Florida sub-regions or hotspots including portions of the Everglades (Rumbold 2019b).

Mercury in mosquitofish was lower in 2014 than in 2005, which was lower than in 1995. This result is suggested by krigs, and confirmed by box-and-whisker plots and the Wald F test for differences between means in the CDF curves (Figures 69-71). In 2014, the proportion of the Everglades marsh that was above the 77 $\mu\text{g}/\text{kg}$ predator protection level was $13.0 \pm 5.7\%$ (Figure 71), as compared to $64.7 \pm 7.3\%$ in 2005 and $70.5 \pm 7.1\%$ in 1995. In 2014, $6.5 \pm 4.2\%$ of the marsh had mosquitofish mercury concentrations that

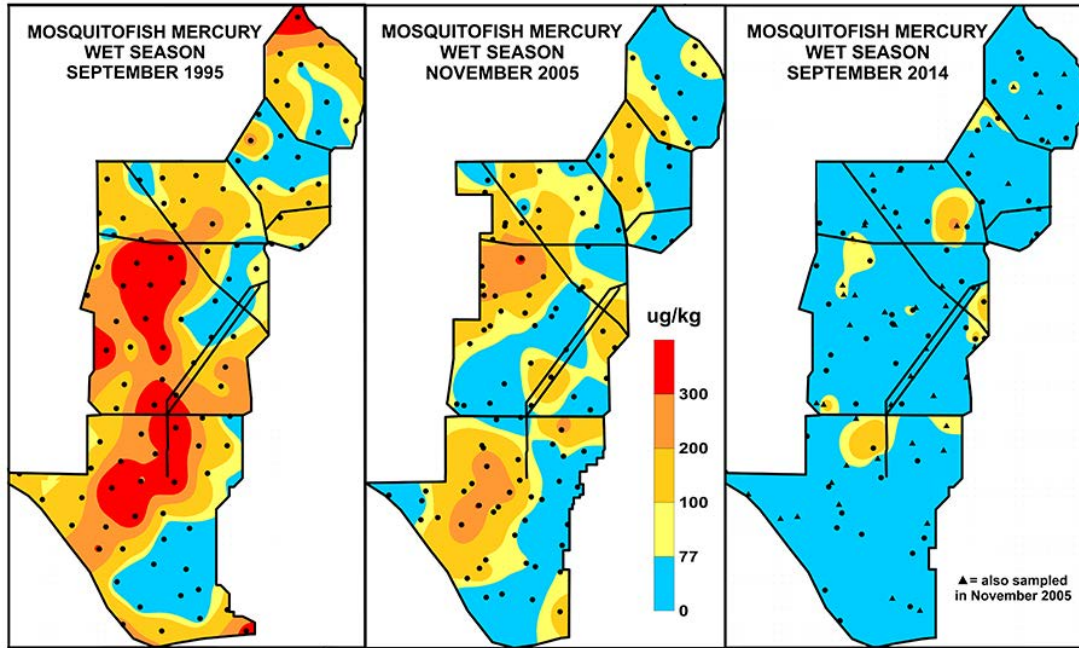
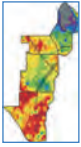


Figure 69. Total mercury concentration in mosquitofish ($\mu\text{g}/\text{kg}$) during Everglades REMAP wet season sampling events: September 1995 (left), November 2005 (middle) and September 2014 (right).

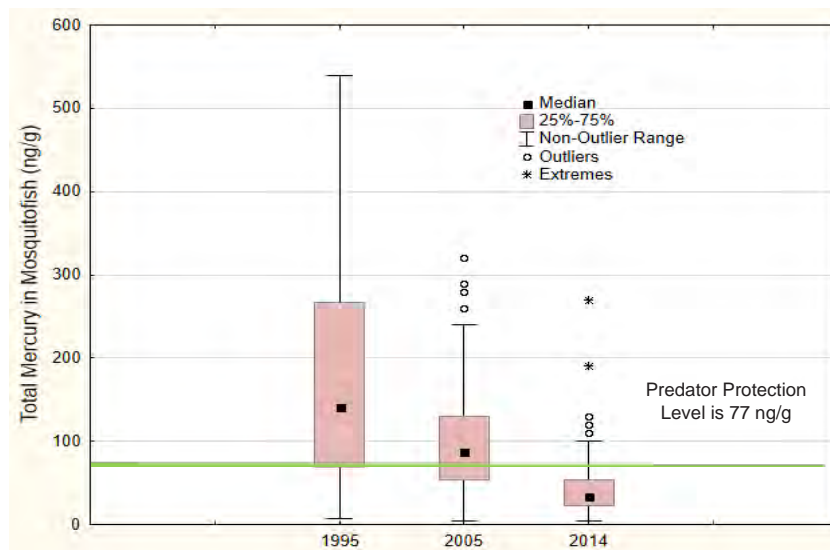
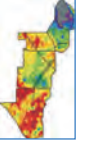


Figure 70. Box and whisker plot of total mercury concentration in mosquitofish (ng/g) during Everglades REMAP wet season sampling events: September 1995 (left), November 2005 (middle) and September 2014 (right).



Mercury concentrations in preyfish in 2014 were lower than in 2005, which was lower than 1995. Concentrations in some locations were still too high to protect top carnivores such as birds. Concentrations in largemouth bass remain high.

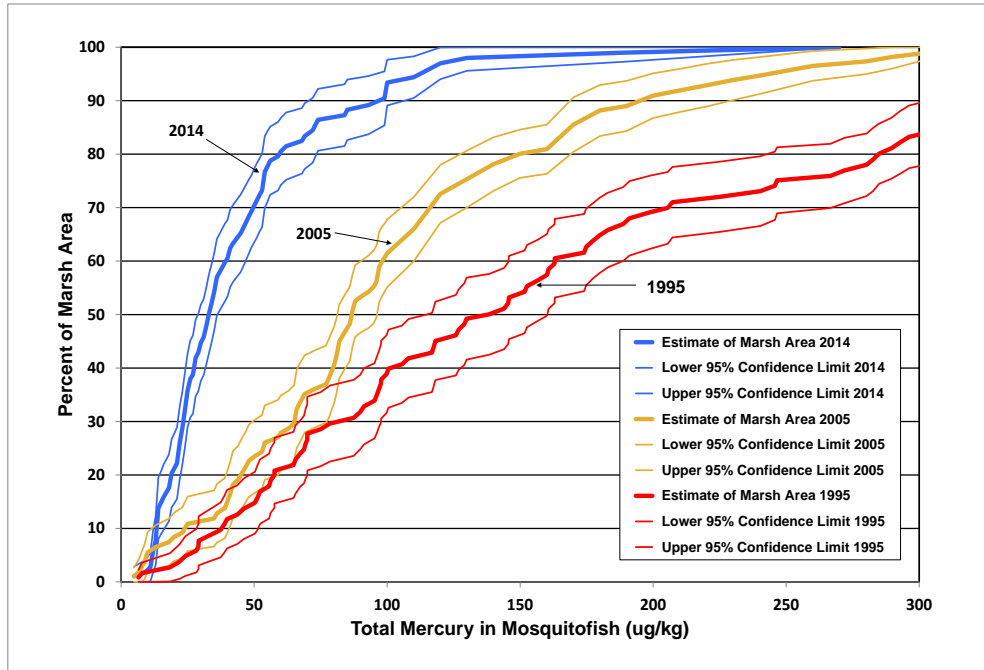


Figure 71. Estimates of marsh area for wet season total mercury concentration in mosquitofish ($\mu\text{g}/\text{kg}$) during Everglades REMAP wet season sampling events: September 1995, November 2005 and September 2014. The estimates indicate improved conditions for mosquitofish in 2005 and 2014 (Wald F test).

exceeded the $100 \mu\text{g}/\text{kg}$ protection level for predators, as compared to $40.1 \pm 6.7\%$ in 2005 and $59.9 \pm 7.3\%$ in 1995. The differences among the curves are statistically significant (Wald F, $p < 0.05$). The changes for the entire Everglades also apply to each subarea (ENP and the three WCAs), as the CDFs for each subarea in 2014 are all different than in 2005 and 1995 (Wald F, $p < 0.04$) (Kalla and Scheidt 2017). Analysis of variance indicated that the lower concentrations observed in 2014 compared to 2005 cannot be explained by fish length or weight. WY15 mercury concentrations reported by FDEP and SFWMD in mosquitofish from 13 locations in the Everglades marsh had an overall median concentration of $44 \mu\text{g}/\text{kg}$ (Julian et al. 2016b), which is consistent with the median of $33.5 \mu\text{g}/\text{kg}$ for 2014 REMAP data.

In spite of the drop in mosquitofish mercury in REMAP data for the three years sampled, overall annual concentrations of mercury in largemouth bass in the Everglades were unchanged from WY99 to WY14 (Julian et al. 2016b), indicating that biomagnification in the food chain remained high. Bass at 6 of 9 locations sampled in 2014 exceeded the $0.3 \text{ mg}/\text{kg}$ fish tissue criterion to protect human health, with the highest median concentration of $1.66 \text{ mg}/\text{kg}$ in bass from Shark River Slough in the Park. From 2000 to 2017, 79% of the largemouth bass across the WCAs and nearly 99% of the bass in the Park in Shark River Slough exceeded the $0.3 \text{ mg}/\text{kg}$ human health criterion (Lange 2019).

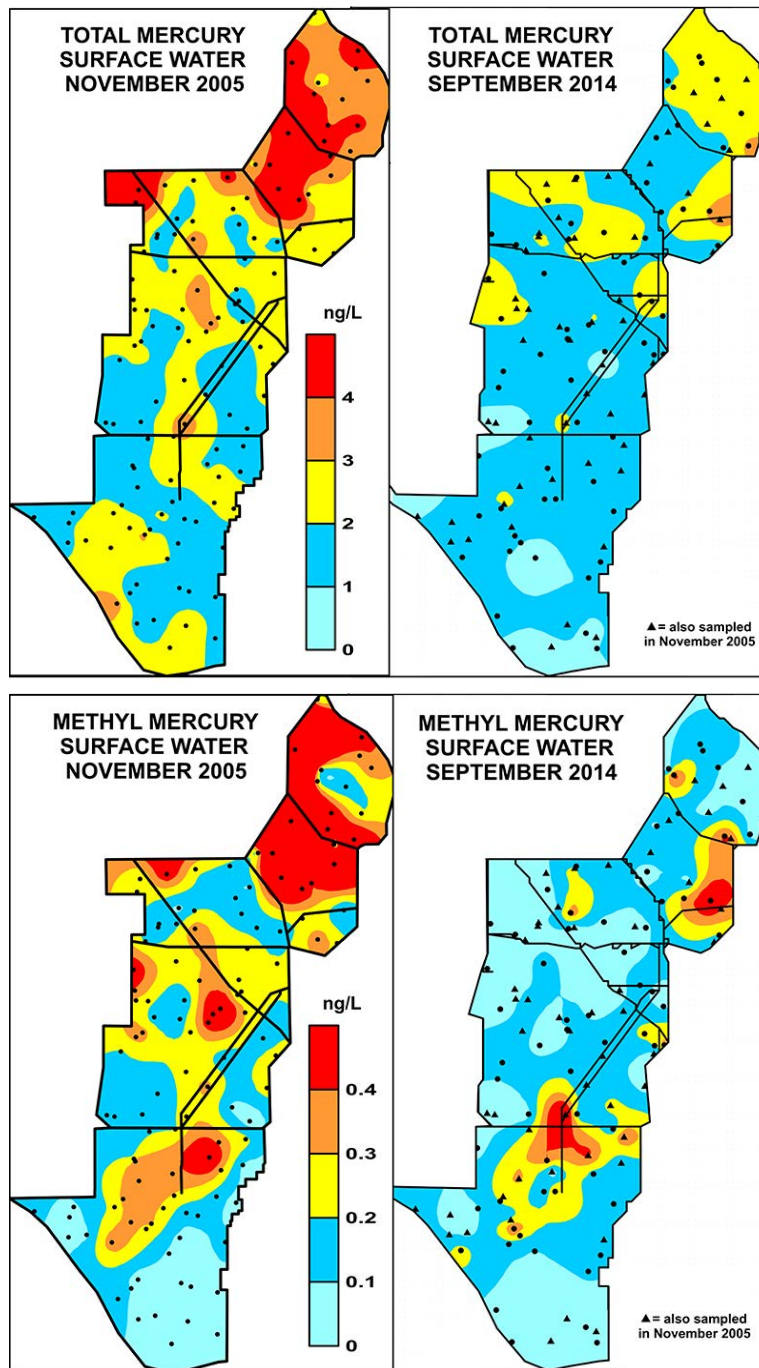
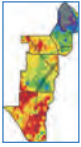


Figure 72. Total mercury (top) and methylmercury (bottom) in surface water (ng/L) during Everglades REMAP wet season sampling events: November 2005 (left) and September 2014 (right).

Total mercury in surface water was also lower during 2014 (Figures 72-73). As compared to 1995, there was a slight increase in 2005 and a larger decrease in 2014, with both differences significant (Wald F, $p < 0.05$). The drop over the whole study area comparing 2014 to 2005 also applies to all four subareas (Wald F, $p < 0.01$)

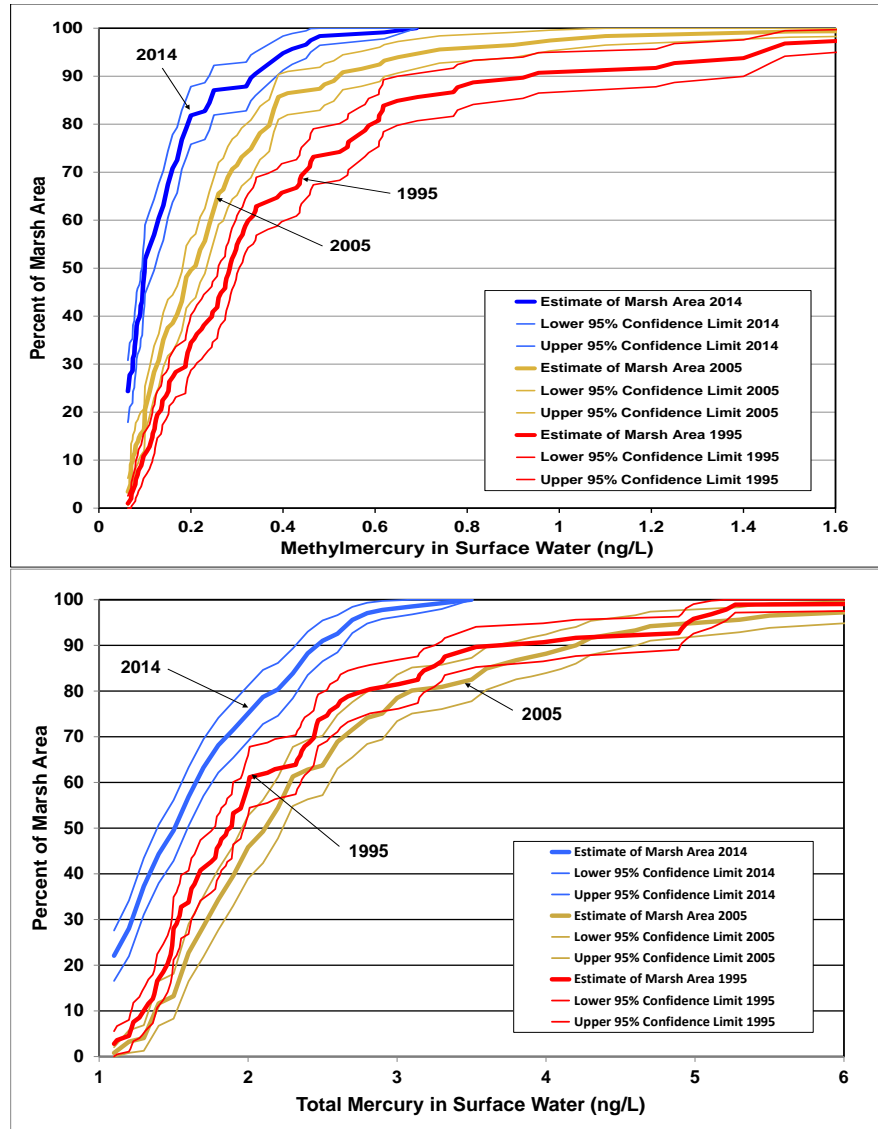
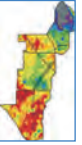


Figure 73. Estimates of marsh area for wet season methylmercury (top) and total mercury (bottom) concentrations in surface water (ng/L) during Everglades REMAP wet season sampling events: September 1995, November 2005 and September 2014. The estimates indicate improved conditions in 2014 (Wald F test).

(Kalla and Scheidt 2017). Methylated mercury is present in concentrations that are an order of magnitude less than total mercury (2014 median of 0.1 ng/L vs. 1.6 ng/L). There was also less methylmercury in surface water over the course of the 1995, 2005 and 2014 REMAP surveys (Figures 72-73), and the differences among the CDF curves are statistically significant (Wald F, $p < 0.05$). The changes for the whole study area also apply to the three WCAs for 2014 compared to 2005 (Wald F, $p < 0.02$), and for 2014 compared to 1995 (Wald F, $p < 0.01$) (Kalla and Scheidt 2017). USGS data for the Park from 2008 to 2013 show interannual variation with no apparent trend in surface water total mercury or methylmercury (Maglio et al. 2015).

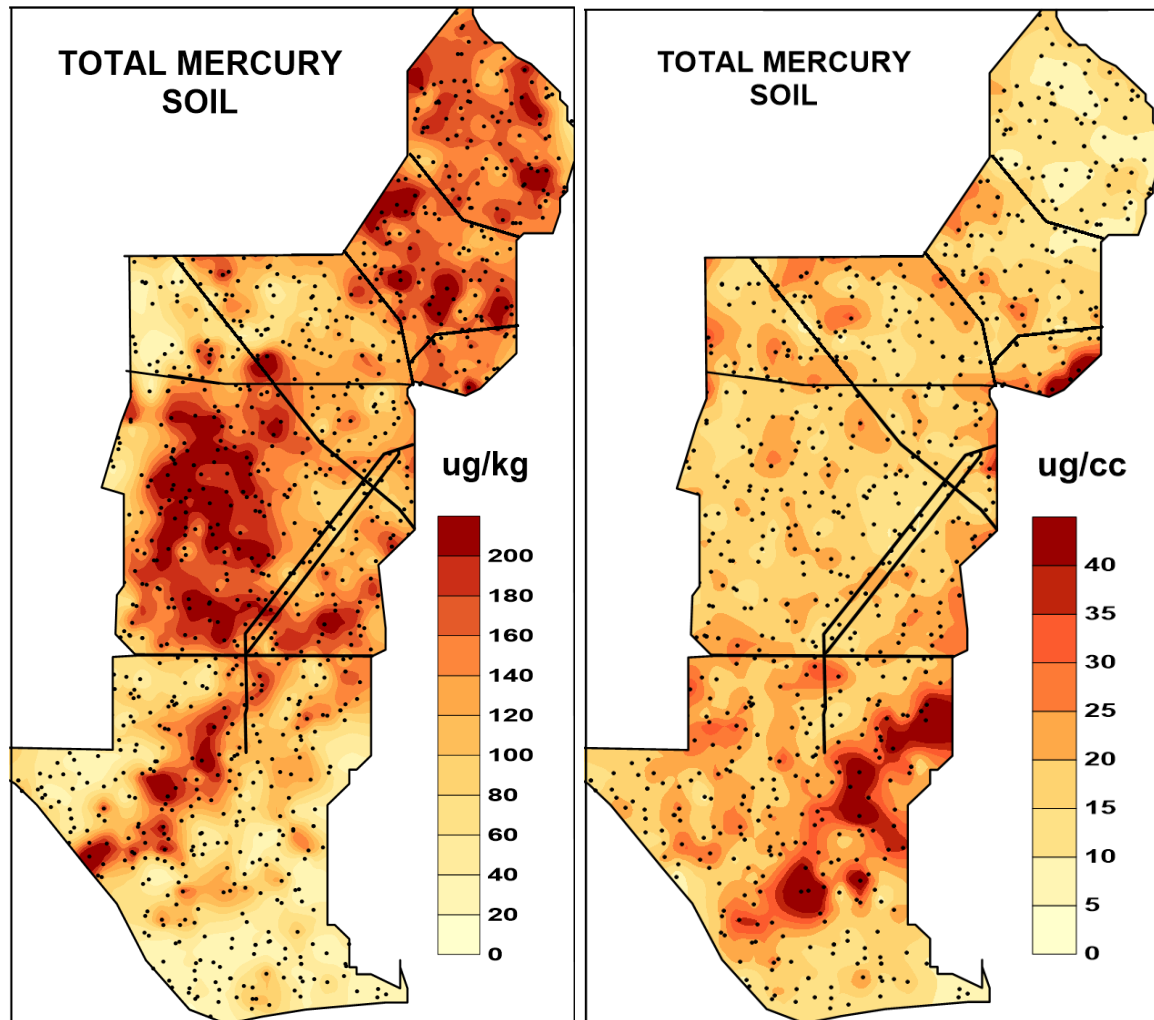
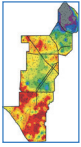


Figure 74. Total mercury in soil for REMAP data from all sampling events, 1995 to 2014, expressed as micrograms of mercury per kilogram of soil (left), and micrograms of mercury per cubic centimeter of soil (right).

Lower mercury in surface water during 2014 cannot be easily attributed to less atmospheric deposition. Most total mercury in surface water consists of inorganic mercury deposited from the atmosphere (reviewed in Liu et al. 2008a). Atmospheric deposition of mercury is influenced by precipitation, local sources, global sources and air circulation patterns. Although a decline in global atmospheric mercury emissions has been reported in recent years (Zhang et al. 2016), annual wet deposition of mercury in the Everglades remained relatively constant from WY94 to WY14 (Julian et al. 2016b). Likewise, data from the Mercury Deposition Network of the National Atmospheric Deposition Program monitoring station within Everglades National Park indicate no difference in mercury loading for 2005 versus 2014 (Kalla and Scheidt 2017).

Mass budget estimates indicate that by far the soil contains the largest pool of mercury in the Everglades, as compared to water, periphyton, floc, or macrophytes (Stober et al. 2001b; Liu et al. 2008a, 2015). Total

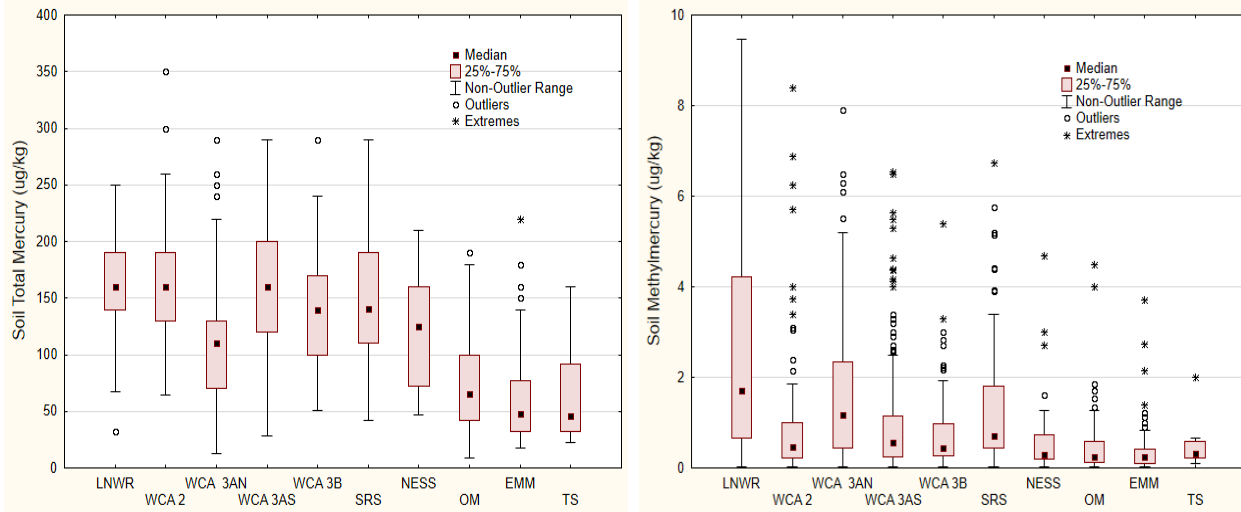
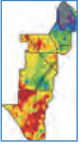
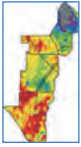


Figure 75. Box and whisker plots of soil total mercury ($\mu\text{g}/\text{kg}$, left) and methylmercury ($\mu\text{g}/\text{kg}$, right) by subarea, all sampling events from 1995 to 2014.

mercury in soil (average of three cores, 0-10 centimeter soil depth) can be expressed on a mass basis (micrograms of mercury per kilogram of soil, median = $130 \mu\text{g}/\text{kg}$), or on a volume basis (micrograms of mercury per cubic centimeter of soil, median = $17.9 \mu\text{g}/\text{cc}$) (Figures 74-75). When expressed by mass, the higher mercury concentrations occur in the peat soils with higher organic matter content (Figures 56 and 74). These results have a similar landscape pattern as data obtained during 2003-04 by others (Cohen et al. 2009b). The mass of total mercury in the Everglades 0-10 cm soil profile has been reported at 13,482 kg using REMAP data (Liu et al. 2015), and 13,000 kg by others (Cohen et al. 2009b).

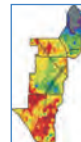
REMAP data continue to indicate high mercury biomagnification. September 2014 median concentrations for total mercury were: surface water, 1.6 parts per trillion; water column periphyton, 19 ppb; benthic periphyton, 24 ppb; mosquitofish, 33.5 ppb; floc, 120 ppb; and soil 150 ppb (Appendix II). Median MeHg concentrations were: surface water 0.1 parts per trillion, water column periphyton 1.8 ppb; benthic periphyton 0.51 ppb; floc 2.6 ppb; and soil 0.77 ppb. The bioconcentration factor expresses the degree to which mercury accumulates in fish compared to its concentration in surface water. Bioconcentration factors were calculated as the concentration of mercury in mosquitofish divided by the concentration of MeHg in surface water (BCF_m). In 2014 the median BCF_m was 340,000 as compared to 410,000 in 2005.

Nonparametric Spearman rank correlations showed that in 2014 no single REMAP variable had a statistically robust association with mercury in mosquitofish (rho coefficient > 0.7 , $p < .001$) Kalla and Scheidt 2017), although several associations were found in 2005 (Scheidt and Kalla 2007). This result may be due to mosquitofish being exposed to mercury by somewhat different pathways in 2005 versus 2014. This result also could simply reflect the decrease and tighter range in mosquitofish mercury concentrations in 2014. The potential influences of water quality parameters, such as DOC and sulfur, on mercury methylation and mercury bioconcentration to fish and wildlife are discussed in the carbon and sulfur sections of this report.



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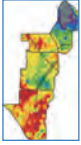
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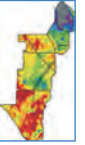
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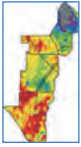
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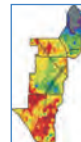
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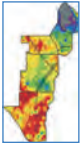
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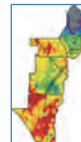
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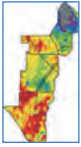
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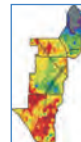
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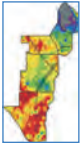
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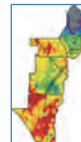
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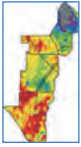
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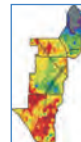
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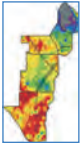
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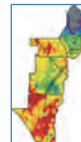
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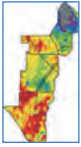
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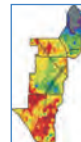
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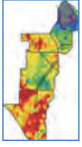
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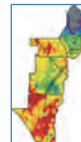
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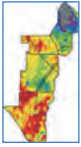
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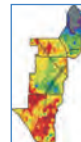
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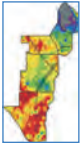
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Appendix I. Everglades REMAP 2014 Measurements and Analytes by Media.

SURFACE WATER (SW)

Depth
Temperature
Dissolved Oxygen
pH
Conductivity
Turbidity
Total Phosphorus
Soluble Reactive Phosphorus
Total Nitrogen
Total Inorganic Nitrogen
Total Organic Nitrogen
Filtered Ammonia
Filtered Nitrate
Filtered Nitrite
Filtered Nitrate-Nitrite
Dissolved Organic Carbon
Total Organic Carbon
Chlorophyll a
Sulfate
Chloride
Methylmercury
Total Mercury

BOTTOM WATER (BW)

Sulfide

SOIL (SD)

Type
Thickness
pH
Ash Free Dry Weight
Bulk Density
Water Content
Total Phosphorus
Total Carbon
Total Nitrogen
Total Mercury
Methylmercury

FLOC (FC)

Thickness
Ash Free Dry Weight
Bulk Density
Water Content
Total Carbon
Total Nitrogen
Total Phosphorus
Total Mercury
Methylmercury
Chlorophyll a

PERIPHYTON [PB (benthic);

PC = PF (floating) + PE (Epiphytic)]

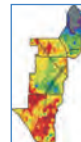
Ash Free Dry Weight
Bulk Density
Total Carbon
Total Nitrogen
Total Phosphorus
Methylmercury
Total Mercury
Chlorophyll a

VEGETATION

Sawgrass Total Mercury
Sawgrass Methylmercury
Sawgrass Total Phosphorus
Sawgrass Total Carbon
Sawgrass Total Nitrogen
Vegetation Type
Dominant Macrophyte
Cattail Presence

MOSQUITOFISH

Total Mercury

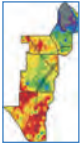


Appendix II. Everglades REMAP Median Values of Selected Wet Season Parameters.

Analyte	Medium	Year			Units*
		1995	2005	2014	
Total Phosphorus	surface water	11.6 ^a	7.50 ^b	6.6 ^c	ug/L
Total Phosphorus	soil	325 ^a	390 ^b	390 ^b	mg/kg
Total Mercury	mosquitofish	141 ^a	87 ^b	33.5 ^c	ng/g
Total Mercury	surface water	1.9 ^a	2.2 ^b	1.6 ^c	ng/L
Methylmercury	surface water	0.28 ^a	0.21 ^b	0.1 ^c	ng/L
Total Mercury	water column periphyton	18 ^a	19 ^a		ng/g
Methylmercury	water column periphyton		1.66 ^a	1.8 ^a	ng/g
Total Mercury	floc		130 ^a	120 ^b	ng/g
Methylmercury	floc		2.95 ^a	2.55 ^a	ng/g
Total Mercury	benthic periphyton		9.70 ^a	24 ^a	ng/g
Methylmercury	benthic periphyton		0.466 ^a	0.505 ^b	ng/g
Total Mercury	soil	120 ^a	140 ^a	150 ^a	ug/kg
Methylmercury	soil	0.44 ^a	0.49 ^a	0.77 ^b	ng/g

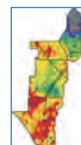
^{a b c} Distributions with medians having different letters are different ($P \leq 0.05$).

* 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 kilogram [(ug/kg), parts per billion], milligrams per liter [(mg/L), parts per million].



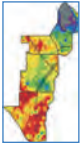
Appendix III. Water quality characteristics by subarea for REMAP dry season sampling events 1995, 1996, 1999 and 2005.

Subarea	Analyte	Number of Samples	Minimum	Maximum	Median	Mean ± Standard Deviation	Standard Error	95% Confidence Interval
DRY SEASON								
LNWR	Chloride (mg/L)	11	21	75	39.0	37.7 ± 16.4	4.9	11.0
WCA2		11	73	200	140.0	132.6 ± 40.7	12.3	27.3
WCA3N		9	38	72	58.0	55.9 ± 11.2	3.7	8.6
WCA3S		48	15	84	50.0	50.4 ± 18.4	2.7	5.3
ENP		16	35	110	60.0	60.8 ± 20.0	5.0	10.7
LNWR	Conductivity (umhos/cm)	30	78.1	717	183.5	226.5 ± 148.9	27.2	55.6
WCA2		27	539	1610	894.0	941.6 ± 243.2	46.8	96.2
WCA3N		23	148	1281	520.0	607.7 ± 273.1	56.9	118.1
WCA3S		111	231	807	527.0	520.4 ± 132.4	12.6	24.9
ENP		58	307	823	587.5	572.7 ± 119.4	15.7	31.4
LNWR	pH	30	5.33	7.33	6.3	6.4 ± 0.5	0.1	0.2
WCA2		27	6.85	8.06	7.5	7.53 ± 0.31	0.1	0.1
WCA3N		23	6.91	8.05	7.4	7.4 ± 0.3	0.1	0.1
WCA3S		111	6.46	7.88	7.3	7.3 ± 0.3	0.0	0.0
ENP		58	6.79	8.25	7.4	7.4 ± 0.3	0.0	0.1
LNWR	Sulfate (mg/L)	30	0.039	14	2.0	2.49 ± 3.0	0.6	1.1
WCA2		27	4.3	73	38.0	37.6 ± 19.3	3.7	7.7
WCA3N		23	2	42	7.0	12.5 ± 12.8	2.7	5.5
WCA3S		111	0.029	36	2.0	4.0 ± 6.5	0.6	1.2
ENP		59	0.16	83	2.0	4.46 ± 10.9	1.4	2.8
LNWR	Total organic carbon (mg/L)	30	15.12	57.14	25.0	28.5 ± 9.8	1.8	3.7
WCA2		27	25.81	50.38	38.6	37.5 ± 7.9	1.5	3.1
WCA3N		23	18	62.98	25.4	28.4 ± 11.0	2.3	4.8
WCA3S		105	11	54.68	22.9	23.8 ± 7.1	0.7	1.4
ENP		59	11.53	49	25.0	25.1 ± 7.7	1.0	2.0



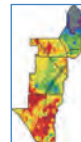
Appendix III (continued). Water quality characteristics by subarea for REMAP wet season sampling events 1995, 1996, 1999, 2005 and 2014.

Subarea	Analyte	Number of Samples	Minimum	Maximum	Median	Mean ± Standard Deviation	Standard Error	95% Confidence Interval
WET SEASON								
LNWR	Chloride (mg/L)	36	5.9	140	19.0	29.5 ± 31.4	5.2	10.6
WCA2		34	46	260	89.5	101.9 ± 48.7	8.3	17.0
WCA3N		46	12	97	38.5	45.7 ± 20.2	3.0	6.0
WCA3S		102	4.6	80	28.0	33.7 ± 18.2	1.8	3.6
ENP		106	5.4	89	32.5	36.5 ± 20.5	2.0	3.9
LNWR	Conductivity (umhos/cm)	57	37.1	1205	102.0	223.7 ± 281.9	37.3	74.8
WCA2		56	302	1423	706.0	764.1 ± 291.5	39.0	78.1
WCA3N		69	165	801	456.0	490.7 ± 165.8	20.0	39.8
WCA3S		161	125	704	383.0	406.2 ± 136.5	10.8	21.3
ENP		175	72	655	372.0	378.9 ± 119.1	9.0	17.8
LNWR	pH	57	5.66	7.39	6.4	6.5 ± 0.5	0.1	0.1
WCA2		56	6.77	7.88	7.3	7.3 ± 0.3	0.0	0.1
WCA3N		70	6.69	7.88	7.2	7.2 ± 0.2	0.0	0.1
WCA3S		161	6.77	8.36	7.3	7.3 ± 0.3	0.0	0.0
ENP		175	6.9	8.39	7.7	7.7 ± 0.3	0.0	0.0
LNWR	Sulfate (mg/L)	57	0.022	66	1.2	6.9 ± 15.1	2.0	4.0
WCA2		56	2.9	110	26.5	34.3 ± 26.3	3.5	7.1
WCA3N		70	0.12	52	5.7	13.1 ± 14.8	1.8	3.5
WCA3S		161	0.012	39	1.8	4.0 ± 6.2	0.5	1.0
ENP		175	0.009	16	1.4	2.2 ± 2.7	0.2	0.4
LNWR	Total organic carbon (mg/L)	57	10.11	44.53	18.0	20.4 ± 7.9	1.0	2.1
WCA2		56	17.19	51.6	29.0	30.3 ± 9.2	1.2	2.5
WCA3N		70	12	35.39	20.6	21.9 ± 6.0	0.7	1.4
WCA3S		161	7.9	29.63	16.7	16.7 ± 4.3	0.3	0.7
ENP		175	4.6	31	12.0	13.2 ± 5.1	0.4	0.8



Appendix IV. Soil characteristics by subarea for REMAP 1995, 1996, 1999, 2005 and 2014.

Subarea	Analyte	Number of Samples	Minimum	Maximum	Median	Mean ± Standard Deviation	Standard Error
LNWR	Thickness (feet)	105	1.30	14.00	8.57	8.75 ± 2.59	0.25
WCA 2		103	0.93	8.60	4.10	4.25 ± 1.60	0.16
WCA 3AN		129	0.20	5.20	1.60	1.74 ± 1.04	0.09
WCA 3AS		223	0.05	7.40	2.90	2.85 ± 1.33	0.09
WCA 3B		78	1.00	6.53	3.25	3.51 ± 1.33	0.15
SRS		67	0.10	5.70	1.50	1.73 ± 1.12	0.14
NESS		44	0.10	4.30	1.64	1.67 ± 1.09	0.17
OM		79	0.00	4.77	0.83	1.10 ± 0.88	0.10
EMM		134	0.00	7.33	0.70	1.01 ± 1.11	0.10
TS		13	0.90	7.83	3.00	3.26 ± 2.07	0.58
LNWR	Organic Matter (percent)	101	25.00	98.83	93.77	91.51 ± 10.51	1.05
WCA 2		103	20.58	100.00	87.00	82.92 ± 13.61	1.34
WCA 3AN		128	9.79	98.55	75.30	64.96 ± 24.57	2.17
WCA 3AS		224	1.19	98.70	87.85	80.52 ± 17.41	1.16
WCA 3B		78	30.48	93.65	82.34	74.98 ± 16.88	1.91
SRS		67	12.00	91.24	78.00	66.58 ± 22.78	2.78
NESS		44	13.51	90.55	44.86	51.58 ± 25.87	3.90
OM		78	10.07	79.64	31.89	33.82 ± 15.66	1.77
EMM		133	1.57	85.14	20.57	24.80 ± 15.62	1.35
TS		13	10.54	93.73	21.84	39.24 ± 31.45	8.72
LNWR	Bulk Density (g/cc)	79	0.04	0.16	0.06	0.07 ± 0.02	0.00
WCA 2		79	0.05	0.43	0.10	0.11 ± 0.06	0.01
WCA 3AN		99	0.08	0.90	0.17	0.22 ± 0.16	0.02
WCA 3AS		171	0.06	0.50	0.11	0.12 ± 0.06	0.00
WCA 3B		60	0.05	0.32	0.14	0.14 ± 0.04	0.01
SRS		53	0.07	0.44	0.13	0.15 ± 0.08	0.01
NESS		35	0.08	0.88	0.21	0.25 ± 0.16	0.03
OM		59	0.11	0.73	0.30	0.32 ± 0.14	0.02
EMM		104	0.06	0.79	0.45	0.44 ± 0.16	0.02
TS		8	0.11	0.51	0.27	0.30 ± 0.13	0.05



Appendix IV (continued). Soil characteristics by subarea for REMAP 1995, 1996, 1999, 2005 and 2014.

Subarea	Analyte	Number of Samples	Minimum	Maximum	Median	Mean ± Standard Deviation	Standard Error	95% Confidence Interval	
LNWR	Methyl Mercury (ug/kg)	87	0.02	9.47	1.70	2.54 ± 2.41	0.26	0.51	
WCA 2		89	0.02	8.40	0.46	1.00 ± 1.53	0.16	0.32	
WCA 3AN		126	0.02	7.90	1.17	1.67 ± 1.62	0.14	0.29	
WCA 3AS		214	0.02	6.54	0.57	0.97 ± 1.20	0.08	0.16	
WCA 3B		74	0.02	5.40	0.44	0.81 ± 0.94	0.11	0.22	
SRS		63	0.02	6.74	0.72	1.43 ± 1.57	0.20	0.40	
NESS		44	0.02	4.69	0.29	0.62 ± 0.89	0.13	0.27	
OM		73	0.02	4.50	0.24	0.51 ± 0.76	0.09	0.18	
EMM		121	0.02	3.71	0.24	0.37 ± 0.50	0.05	0.09	
TS		9	0.11	2.00	0.31	0.51 ± 0.59	0.20	0.45	
LNWR		Total Mercury (ug/kg)	104	32.00	250.0	160.0	161.7 ± 40.0	3.92	7.78
WCA 2	102		64.00	350.0	160.0	165.6 ± 49.0	4.85	9.63	
WCA 3AN	128		13.00	290.0	110.0	108.0 ± 54.2	4.79	9.49	
WCA 3AS	222		28.00	290.0	160.0	159.9 ± 52.4	3.52	6.93	
WCA 3B	77		51.00	290.0	140.0	138.9 ± 46.4	5.28	10.52	
SRS	67		42.00	290.0	140.2	150.3 ± 59.2	7.23	14.44	
NESS	44		47.00	210.0	125.0	120.3 ± 50.0	7.54	15.22	
OM	79		9.30	190.0	65.0	76.7 ± 42.6	4.79	9.53	
EMM	133		17.22	220.0	48.0	63.9 ± 43.8	3.80	7.52	
TS	13		22.00	160.0	46.0	65.3 ± 45.5	12.62	27.50	
LNWR	Total Nitrogen (percent)		38	2.40	4.60	3.10	3.28 ± 0.58	0.09	0.19
WCA 2		36	0.58	3.70	3.10	2.84 ± 0.75	0.13	0.25	
WCA 3AN		46	0.61	3.90	3.00	2.81 ± 0.76	0.11	0.23	
WCA 3AS		77	1.20	4.72	3.30	3.30 ± 0.66	0.07	0.15	
WCA 3B		31	1.21	3.90	2.90	2.65 ± 0.77	0.14	0.28	
SRS		27	0.90	3.80	2.80	2.61 ± 0.89	0.17	0.35	
NESS		15	0.93	3.30	1.80	1.98 ± 0.91	0.24	0.51	
OM		25	0.64	3.10	1.40	1.49 ± 0.68	0.14	0.28	
EMM		43	0.21	1.80	0.78	0.86 ± 0.35	0.05	0.11	
LNWR		Total Phosphorus (mg/kg)	79	183.6	1400.0	327.3	387.4 ± 187.9	21.14	42.10
WCA 2			77	110.0	1591.6	410.0	484.2 ± 274.3	31.25	62.25
WCA 3AN	101		97.2	1701.8	480.0	523.7 ± 286.6	28.52	56.58	
WCA 3AS	172		115.7	880.0	390.4	413.9 ± 135.7	10.35	20.43	
WCA 3B	60		125.6	1700.0	353.5	399.7 ± 239.0	30.86	61.75	
SRS	53		170.7	771.8	381.9	401.8 ± 130.2	17.88	35.88	
NESS	35		128.4	750.0	315.5	333.7 ± 140.0	23.66	48.08	
OM	59		152.1	956.9	339.1	391.0 ± 196.9	25.64	51.32	
EMM	104		55.7	1332.2	240.0	303.3 ± 250.5	24.56	48.71	
TS	8		83.7	610.0	192.4	220.2 ± 167.7	59.28	140.17	