Appendix 6-1: Environmental Responses to Water Management: A Strategic Research Plan for the Everglades Division

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INTRODUCTION AND BACKGROUND

The mission of the South Florida Water Management District is "to manage and protect water resources of the region by balancing and improving water quality, flood control, natural systems and water supply." Environmental science provides much of the basis for defining and deciding the nature of this balance and effectively improving management for each of these often competing missions. Within this framework, the mission of the Everglades Division is to provide the best possible scientific basis for environmental management by designing and conducting high quality applied and innovative science to sustain, restore and manage the Everglades ecosystem, including its estuaries. Through interdisciplinary and integrated monitoring, research and modeling, the District strives to:

- quantify and assess the status and trends of the ecosystem;
- determine the causes of ecosystem change, especially distinguishing the effects of water management from the effects of other human activities and natural forces;
- and forecast the future state of the ecosystem and ecosystem change as a function of changing water management.

In the plan presented here, the District presents a first draft of a roadmap for the Everglades Division's scientific activities over the next five years. The District focuses on efforts that will increase the agency's understanding of the response of the Everglades ecosystem to the primary manageable drivers of this system – hydrologic conditions (including spatial and temporal patterns of stage, hydroperiod, and flow) and water quality (Sklar et al., 2002; Davis et al., 2005a; Davis et al., 2005b; Ogden, 2005; Ogden et al., 2005; Rudnick et al., 2005; Sklar et al., 2005). Virtually all District projects regarding Everglades management strive to "get the water right" in terms of quantity, timing, distribution, and quality; this appendix describes how we intend to relate these hydrologic and water quality drivers (including their variability and their interactions) to the ecological condition and trajectory of the Everglades ecosystem.

Given the geographic extent and ecological complexity of the Everglades, priorities regarding topical and regional focus need to be defined. The Strategic Research Plan calls for a focus on understanding four general sets of Everglades components or functions that are strongly affected by water management:

1. Food webs that support wildlife, including the dynamics of wading birds.

2. The nature of areas that have already been impacted by phosphorus enrichment and how these areas can be managed to accelerate ecological recovery.

3. Ecosystem processes related to controls of soil dynamics (accretion or subsidence, especially in the central Everglades and in coastal wetlands) and the functional linkage of the Everglades and Florida Bay.

4. The structure and function of major landscape features, especially tree islands, ridge-and-slough alternations, and mangrove zone plant communities.

Implementation of the scientific projects described in each of the four sections of this plan will directly serve District programs and projects, especially fulfilling the needs and mandates of the statutory The Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area and Tributary Basins (Long-Term Plan) to achieve water quality goals, the

Comprehensive Everglades Restoration Plan (CERP), and Minimum Flows and Levels (MFLs). The *2007–2017 Strategic Plan* of the District explicitly identifies priority needs and directives for District programs, including:

- Implementation of the Long-Term Plan with identification of options for accelerated recovery—this goal is addressed in the Accelerated Recovery Section (#2 above).
- The Everglades Program and CERP (two of the main functional/budgetary programs within the Everglades Division) call for the restoration of more natural flows and levels within the Everglades and restoration of the ecology and natural function of the Everglades—these complex goals are addressed in each of the four sections of the Everglades Division's Strategic Research Plan.
- The Coastal Watersheds Program (pertaining to Florida Bay within the Everglades Division) calls for development of technical criteria for MFLs—this goal is addressed in Food Web and Ecosystem Processes Sections (#1 and #3 above).

The proposed focus of the four sections of this plan follows from the Division's history of Everglades research and extensive planning associated with CERP (especially RECOVER). Most notably, the inter-agency Restoration Coordination and Verification team (RECOVER) has identified critical performance measures and uncertainties (CERP Monitoring and Assessment Plan, Part 1, 2004). Each section of the Monitoring and Assessment Plan includes measurements and research of major performance measures and mechanisms that influence these metrics. Furthermore, RECOVER identified an extensive set of hypotheses (which are more similar to restoration expectations than strict hypotheses) and each section explicitly identifies those hypotheses that it proposes to address. It should be noted that RECOVER performance measures and hypotheses were identified during an extensive set of workshops that developed a set of conceptual ecological models for Everglades restoration [for the total system (Ogden, 2005), ridge-and-slough landscape (Davis et al., 2005a), southern marl prairies (Davis et al., 2005a), mangrove-dominated coastal wetlands (Davis et al., 2005b), and Florida Bay (Rudnick et al., 2005). The Strategic Research Plan presented here was informed by these models; proposed projects, in large part, focus on key components and uncertainties identified in the models.

This Appendix 6-1 of Chapter 6 of the *2008 South Florida Environmental Report (SFER) – Volume I*, is the result of several facilitated workshops in 2007 that were designed to prioritize current studies and discuss the implementation of new studies. These workshops were never designed to establish detailed field, laboratory, or numeric processes to fully implement and test. Rather, they were designed to construct teams of technicians, staff, and scientists to address the most pressing needs associated with restoration, operations, regulation, and environmental protection. In this context, the reader is asked to view this plan as an outline and general approach to the restoration, conservation biology and resource management needs of the SFWMD, and not as a scheduled, methodology-burdened, and budgeted project proposal.

This plan and its various experimental, synoptic, and synthetic research projects are integrated around RECOVER hypotheses, which are presented at the beginning of each of the four sections. These should be viewed as guiding topics for restoration and resource management rather than as experimental hypotheses. The description of each project in each section has four elements to facilitate comprehension, they are: (1) Project Overview and Background, (2) Management and Restoration Objectives, (3) Methodological Approach, and (4) Application of Results. **Table 1** provides a guide to the link of each project with the scientific needs of CERP and to the federal and state regulations and policies that supply the appropriations.

Only one element of this plan, Ecological Valuation (EV), is not mandated or listed as a restoration need. However, the District would argue that sometimes mandates do not keep up with scientific results or approaches, and that EV has a role to play in the Adaptive Management Guidelines of the CERP Programmatic Regulations. What is not shown are the linkages that these research projects have with each other. A graphical representation of these relationships would appear as a complex “spaghetti” diagram—but it would in that it would illustrate dependencies and critical paths. The final Strategic Research Plan may well discuss such a conceptual diagram (Ogden et al., 2005).

Table 1. Summary of the Everglades Division Strategic Research Plan in relation to: (1) research goals and objectives, (2) mandates, and (3) RECOVER hypotheses (CERP MAP, Part 2, 2006); EFA = Everglades Forever Act (Florida Statute 373.4592); LTP = The Long-Term Plan of the EFA; MFLs = Minimum Flows and Levels; CERP = Comprehensive Everglades Restoration Plan; SFWMD = South Florida Water Management District. See endnote #2 for the list of RECOVER hypotheses.

PROJECTS	RESEARCH OBJECTIVES	MANDATES	HYPOTHESES[1] (#)
EXAMINING THE FOOD WEB			
Avian Population Responses	Assess recovery of pre-drainage wading bird nesting patterns, and provide information on distribution, abundance and hydrological relationships associated with secretive marsh birds.	CERP; MFL's; SFWMD	#1, #3
Freshwater Prey Availability for Wading Birds	Define food supply limits and determine food limitation as a function of hydrology.	CERP; MFL's; SFWMD	#1, #2, #3
Periphyton Utilization and Dynamics	Trace the carbon products of primary production utilized by heterotrophs within the periphyton complex.	MFL's; EFA; CERP	#4
Prey Availability in the Mangrove Transition Zone	Assess the relationship of forage fish abundance and distribution to salinity and habitat quality.	MFL; CERP; SFWMD	#5
Tracing the Historic use of Tree Islands by Wading Birds	Identify wading bird chemical signatures (e.g., uric acid) that can be used to track historical distributions.	CERP; MFL's	#2
MANAGING FOR ACCELERATED ECOSYSTEM RECOVERY			
The Cattail Habitat Improvement Project (CHIP)	Assess the sustainability of created openings on the development of desirable habitat in areas with invasive cattail and willow.	MFL's SFWMD; LTP	LTP #1
Accelerated Cattail Removal: The Fire Project	Predict the return of sawgrass and ridge communities as a function of fire management alternatives in areas with invasive cattail and willow.	MFL's; SFWMD; LTP	LTP #1
UNDERSTANDING ECOSYSTEM PROCESSES: Microbial and Soil Processes			
Modeling Soil Dynamics	Predict the long-term response of tree island, ridge and slough communities to changes in water depth and flow.	CERP	#6, #8, # 10
Biomarkers and Decomposition	Quantify the alterations in microbial communities in response to changes in hydrology using phospholipid fatty acids (PLFA).	MFL's; EFA	#4, #8, LTP #1
Mineral Impacts on the Soft Water Everglades	Evaluate the ecological impacts and mechanisms associated with shifts to hardwater periphyton communities. Document which freshwater salinity ions account for the observed changes in periphyton structure.	MFL's; SFWMD; EFA	#7
UNDERSTANDING ECOSYSTEM PROCESSES: Florida Bay – Everglades Linkage			
Florida Bay Algal Blooms	Assess the effects of changing fresh water flow on nutrient loading and algal blooms.	EFA; FEIM; CERP; SFWMD	#11
Florida Bay Seagrass and Ecosystem Studies	Assess the effects of changing fresh water flow on seagrass habitat distribution and quality. Understand the causes and potential for die-off of seagrass.	MFLs; CERP; EFA; SFWMD	#11, #12
Submersed Aquatic Vegetation (SAV) Modeling	Evaluate and forecast the effects of changing fresh water flow, in association with changing water quality, on SAV habitat distribution, quality and productivity.	MFLs; CERP; EFA; SFWMD	#12

PROJECTS	RESEARCH OBJECTIVES	MANDATES	HYPOTHESES[1] (#)
LANDSCAPE STRUCTURE AND FUNCTION: Ridge and Slough			
Vegetation Mapping	Conduct comprehensive high resolution, vegetation mapping of the greater Everglades and develop large-scale mapping techniques that capture vegetation height and structure.	CERP	#8, #9, #13
Historic Dynamics of the Landscape Mosaic	Use paleoecological indices to reconstruct temporal changes in hydrology, plant species distributions, and soil accretion rates.	CERP; MFL's	#6, #8, #13
Flow Effects on Plant Community Interactions	Understand the ecological processes associated with hydrology and slough community change.	CERP; MFL's; EFA	#6, #13
Meta-scale Transport Processes: Natural and Manipulated	Create a large-scale hydrologic manipulation to examine sheetflow, sediment transport, slough restoration and tree island resilience. Quantify the threshold of hydrologic velocities that cause floc and sediment transport.	CERP; MFL's; SFWMD; EFA	#6, #8, #13
Ridge & Slough Pattern Analysis and Modeling	Determine spatial pattern changes across a broad range of flow-impacted regions. Create simple relationships between flow, depth and vegetation to explain ridge and slough patterning.	CERP; SFWMD	#8, #13
LANDSCAPE STRUCTURE AND FUNCTION: Tree Islands			
Past and Present Tree Island Elevation Responses to Hydrology	Quantify tree island elevation change in terms of accretion, subsidence, hydrology and productivity and use the paleo-environmental record to determine the hydrological conditions conducive to tree island formation and development.	CERP; MFL's; SFWMD	#6, #8, #10
Tree island Development and Sustainability: Synoptic Studies and LILA Experiments	Assess the hydrological tolerance of tree island vegetation and the effects of hydrology on tree-island degradation patterns. Gain an understanding of basic tree island ecology for the management of water levels to prevent further degradation.	CERP; MFL's	#6, #13
Exotics on Tree Islands: *Lygodium* Impacts and Control	Characterize l*ygodium* spreading mechanisms.	CERP; MFL's; SFWMD; EFA	None
LANDSCAPE STRUCTURE AND FUNCTION: Mangrove Zone			
Freshwater Flow Effects on the Mangrove Transition Zone	Evaluate how changing flow and hydropattern can influence plant communities, rates of soil accretion and counteract sea level rise.	SFWMD; EFA; CERP	#9, #10
SYNTHESIS			
Ecological Valuation	Transform ecological data into economic parameters to support efficient restoration planning.	None	None

EXAMINING THE FOOD WEB

Wildlife populations have played a major role in the protection and management of the Everglades. The high visibility and charisma of birds, panthers, and crocodilians have been used to galvanize public support for the Everglades restoration efforts. Much of the litigation and controversy surrounding the effects of water management on wildlife populations stemmed from a poor understanding of the hydrologic needs of key species. This oversight was addressed in the Everglades Forever Act (EFA), which mandated that the District shall conduct research to understand the hydrologic and ecological needs of the Everglades. CERP uses wildlife populations as performance measures for restoration success and as a basis for setting hydrologic targets. In addition, CERP requires updated information to fine-tune those targets and to identify hydrologic needs of aquatic fauna.

A key group of species in the Everglades is wading birds. These birds exhibit a suite of characteristics that render them particularly suitable for monitoring wetland ecosystem function. They are conspicuous, easy to count, and respond rapidly to hydrologic and other ecological conditions of the ecosystem. As the numerically dominant group of top predators, they have significant affects on food webs through predation and nutrient transport, and can reflect the health of lower trophic levels through their population dynamics. They also range widely over the landscape and have been monitored in the Everglades for over 100 years, allowing comparisons of ecological conditions across large areas of space and time.

Wading bird populations in the Everglades have decreased dramatically over the past 80 years (Crozier and Gawlik, 2002). Accompanying this decline in overall population have been substantial shifts in both the location and reproductive timing of wading bird breeding colonies (Ogden, 1994). Concomitant with these changes in the wading bird community was an alteration in hydroperiod, sheet flow, recession rate and water depth within different parts of the system. Under the ‘food availability’ hypothesis, water management activities have changed the hydrology and decreased the extent of the Everglades, thereby reducing the availability of prey for wading birds, reducing feeding success and ultimately, reproductive output. Prey availability may be reduced by a decrease in the density of prey and/or the vulnerability of prey to capture in foraging areas. Thus, a major focus of the District’s current food web research is to identify the factors, particularly those related to water management, that influence wading bird prey availability and ultimately determine the abundance, distribution and nesting success of individual wading bird species. In addition, certain other taxa that are dependent on aquatic prey resources, such as secretive marsh birds and predatory fishes, will also be examined in this context.

To understand the complexities of wildlife ecology in an Everglades restoration context—multiple temporal and spatial scales, non-linear ecosystem attributes, numerous additional components—this research plan employs a transdisciplinary approach that encompasses studies at multiple levels of the food web over various spatial and temporal scales. The research will concentrate on the core trophic elements of the Everglades ecosystem: top level vertebrate predators (birds and large fish), common aquatic prey species (small fish and invertebrates), and periphyton, potentially the essential base of the food web. Understanding the flux of energy among these trophic layers, particularly in response to hydrologic conditions, will be the key focus of the research. The studies were designed in large part to address the key uncertainties of the RECOVER hypotheses. In short, they will investigate (1) how periphyton is utilized by fish and invertebrates, (2) how hydrology affects the availability of fish and invertebrate prey species to predators in both fresh water marshes and the mangrove transition zone, and (3) how changes in prey availability have changed the spatial distribution of wading bird nesting in the system. This research links logically with studies from other institutions and compliments the overall CERP research effort. Everglades Division studies will variously utilize observational, experimental, and modeling approaches. A synthesis of this information will help guide restoration and operational decisions.

Primary RECOVER hypotheses that will be in addressed in part by the projects described in this section are:

Hypothesis 1: Wading Bird Nesting Colony Location, Size, and Timing

The collapse of wading bird nesting colonies in the tributary headwaters and southern mainland of the Everglades, the abandonment of roseate spoonbill (*Ajaja ajaja*) nesting colonies in islands of northeast Florida Bay, and delay in the annual initiation of wood stork (*Myceteria americana*) nesting have been caused by:

- decreased population densities of marsh fishes and other aquatic prey organisms in the southern Everglades;
- a shift in the location and timing of seasonal concentrations of marsh fishes and other aquatic prey organisms;
- and reduced shallow-water foraging options for wading birds along elevation gradients.

Hypothesis 2: Wading Bird Super Colony Formation

Unusually large aggregations of nesting wading birds (super colonies) consisting of mostly white ibis (*Eudocimus albus*) formed in the pre-drainage system in response to the effects of extreme, natural patterns of drought prior to colony formation.

Hypothesis 3: Aquatic Fauna Dry and Wet Season Prey Concentration

The concentration of marsh fishes and other wading bird prey into high-density patches where wading birds can feed effectively is controlled by the rate of dry-season water-level recession and local topography/habitat heterogeneity. The wet-season density, size structure, and relative abundance of marsh fishes and other aquatic wading bird prey are directly related to the time since the last dry-down and the length of time the marsh was dry. Aquatic prey populations are further affected by salinity in coastal ecotones and by site nutrient status. Responses are non-linear and species specific.

Hypothesis 4: Linkage of Periphyton to Higher Trophic Levels

Periphyton. The complex matrix of algae, bacteria, fungi, and small invertebrates growing in association with macrophytes and sediments, provides critical support of the Everglades food web. The flux of energy and matter to higher trophic levels are directly related to periphyton structure and function which are regulated by local physio-chemical conditions.

Hypothesis 5: Florida Bay Faunal Responses and Nursery Function Hypotheses

CERP implementation will affect the life cycle and abundance of fishery species through habitat dependencies (e.g., food availability and as refugia from predation) and direct physiological effects of salinity upon growth and survival. CERP effects on small prey fish in shallow water SAV habitat will be reflected in the productivity of consumers (e.g., gray snapper) who depend on this forage base and use shoreline mangrove prop-root habitat as shelter.

Avian Population Responses

Project Overview and Background. The decline of wading bird populations was one of the first and most visible signs that the Everglades ecosystem had been degraded. The number of wading bird nests has decreased by an estimated 70 percent since the 1930s, but the population trend appears to be species specific (Crozier and Gawlik, 2002). Most evidence suggests that the decline in nesting effort is related to changes in the region's hydrology, which in turn has changed the way that food becomes available to wading birds (Kahl, 1964; Kushlan, 1976; Fleming et al., 1994; Gawlik, 2002).

Avian population surveys to assess responses to water management and restoration include distributions of secretive marsh birds. The term 'secretive marsh bird' encompasses non-colonial, non-waterfowl aquatic species including bitterns, grebes, rails, gallinules and limpkin. These species primarily inhabit marshes, are dependent on dense emergent vegetation, and are important components of the biodiversity of wetland ecosystems. Some species are federally or state protected (U.S. Fish and Wildlife Service, 2002). Any management activity that alters hydrologic patterns, reduces open water areas, alters aquatic faunal communities, or reduces the amount of emergent plant cover could potentially affect habitat quality for secretive marsh birds. Anecdotal evidence suggests that populations of many species have declined in the Everglades in response to water management practices but insufficient data is available to determine their current status and population trends as a group.

Management and Restoration Objectives. The objectives of this research is to (1) quantify how wading bird populations in the Everglades respond to changes in hydrologic patterns and to (2) conduct a survey of secretive marsh birds throughout the Greater Everglades to estimate population sizes and provide information on distribution, abundance and hydrologic relationships.

Methodological Approach. The project has thee components. The first is to continue compiling wading bird nesting data for all of South Florida on an annual basis. These data are submitted by numerous investigators at no cost to the District and are compiled and analyzed in the form of the annual South Florida Wading Bird Report [(SFWBR) e.g., Cook and Call 2006]. The second component is to continue the current modeling work on wading bird distribution and abundance in the Everglades using long-term data from Systematic Reconnaissance Flights (SRFs). The first phase of the SRF modeling from 1985 through 2000 was recently completed in collaboration with the United States Geological Survey (USGS), Everglades National Park (ENP) and Florida Atlantic University (FAU; see Conroy et al., 2007). In short, a series of models were constructed to evaluate the five principle hypotheses for the decline of wading bird populations: (1) distant magnets, (2) transitional habitats, (3) hydropattern alteration, (4) estuarine degradation, and (5) food availability. The models were also used to predict optimal water levels and drying rates for foraging white ibis and great egret (*Casmerodias albus*). Additional modeling and analyses are needed to address detectability issues and incorporate data from 2001 to 2007, a period of much-improved wading bird reproduction. The third component combines established bird survey techniques with the development of a bioacoustics library and network to get a better understanding of the secretive marsh bird response to hydrology and expected habitat change due to restoration.

Application of Results. Key to restoring wading bird populations is a better understanding of the relationship between hydrologic conditions and wading bird foraging success and how that relationship changes over time and space. The SFWBR was the first effort to evaluate Everglades restoration activities and the compiled data is currently used by CERP as an index of wading bird nesting effort. The SFWBR receives considerable press attention and provides the public with an annual measure of restoration progress. The SRF modeling will greatly improve the capacity of the current models to distinguish between competing hypotheses on wading bird distributions and to fine tune region-specific hydrologic targets. These analyses will be used by CERP to shape hydrologic targets, develop useful performance measures and gauge the progress and success of restoration. The modeling will also help the District fulfill a mandate of the EFA and will reduce the potential for conflict and litigation surrounding the effects of water management on endangered and threatened species. Finally, because wading bird species can be used as a hydrologic yardstick of environmental health, they can be directly linked to District operations.

Successful restoration requires an ecosystem approach rather than a focus on a single taxon. Secretive marsh birds are similar to wading birds in that they are top predators in the system, are sensitive to changes in hydrology and are thus effective indicators of restoration success. The habitat requirements of the two bird groups are very different, however, which means that information on secretive marsh bird populations can improve understanding to the effects of restoration activities on overall avian biodiversity. The project will help the District fulfill a mandate of the EFA and will reduce the potential for conflict and litigation surrounding the effects of water management on listed species.

Freshwater Prey Availability for Wading Birds

Project Overview and Background: A leading explanation for the decline of wading bird populations in the Everglades is that the availability of aquatic prey organisms has changed because of altered hydrologic patterns. Prey availability is linked to the production, concentration and distribution of prey organisms, but there is very little understanding of the specific hydrologic conditions that produce patches of highly available prey.

Management and Restoration Objectives. The objective of this research is to quantify how prey availability changes as a function of water management practices and to predict how wading birds will respond to changes in hydrologic properties.

Methodological Approach: This project has two components. The first is to continue the current white ibis food-supplementation study (see Chapter 6 of this volume for details). This study is the first to test experimentally whether a wading bird species in the Everglades is food limited. It quantifies the consequences of food limitation on nestling growth and survival and links the magnitude of these effects to multi-year changes in hydrologic patterns. The hypotheses are that (1) nestlings from food-supplemented nests should be more successful in terms of growth and survival than those of control nests and, (2) the magnitude of the difference between treatments should be greatest during breeding seasons when hydrologic conditions are poor. The second component is to continue the series of Loxahatchee Impoundment Landscape Assessment (LILA) experiments in collaboration with FAU (see the *Historic Dynamics of the Landscape Mosaic: Paleoecological Studies* section for more information on LILA). The objective is to determine the effects of fish community composition, physical features of the Everglades and hydrologic factors on prey availability during the seasonal drydown. Three sets of experiments focusing on (1) wading bird foraging success (see Chapter 6 of this volume for details), (2) prey concentration events, (3) prey community composition, and (4) prey habitat requirements will be conducted to quantify those effects. The primary objective of the wading bird foraging success experiment is to quantify the effects of water depth, submerged and emergent vegetation density and fish density on the foraging success and habitat use of wading birds. The primary hypothesis is that wading bird foraging will be more successful in habitats with shallow water, low-density vegetation and high fish density. For further details of the LILA studies see the LILA Work Plan.

Application of Results: Water recession rates and depths in the marsh during the dry season can control wading birds. However, the mechanism is not understood. Information on the relationships between hydrologic regimes and wading bird feeding success generated from this project will be used by CERP to fine-tune biologic performance measures and hydrologic targets through the adaptive management process and by the water managers when water routing decisions need to be made during the dry season.

Periphyton Utilization and Dynamics

Project Overview and Background: Periphyton is a ubiquitous component of the Everglades landscape. Comprised of algae, bacteria, fungi, and other microorganisms, periphyton functions vary from serving as the base of the Everglades food web to soil formation (Browder et al., 1994; McCormick et al., 2002). Yet despite a relatively high periphyton standing crop (88.2 g m^{-2}), the Everglades supports a surprisingly low standing stock of invertebrates (0.64 g m^{-2}) and fish (1.2 g m^{-2}) (Turner et al., 1999). A review of the Everglades food web, presented in the 2003 Everglades Consolidated Report, concluded that the base of the Everglades food web has yet to be identified for the dominant invertebrates and fish. Results were inconclusive. Some studies indicated that for taxa that consumed periphyton, there was a tendency to select for diatoms and green algae and not for cyanobacteria. Alternatively, detritus appeared to be a major component of some invertebrate diets. Since periphyton is a complex matrix of autotrophic and heterotrophic organisms living in close association, it is likely that secondary production may selectively utilize individual components (e.g., diatoms or bacteria) or biologically derived products (e.g., extracellular polymeric substances). Thus, the challenge is twofold. First, quantify how the energy fixed by autotrophs within the periphyton matrix is utilized by both internal (bacteria and small invertebrates) and external (invertebrates and fish) heterotrophs. Second, determine how changes in environmental conditions affect autotrophic production and what the consequence may be for the transfer of energy and matter to higher trophic levels.

Management and Restoration Objectives: The EFA mandates that water management activities cause no imbalance in Everglades's flora or fauna. The Long-Term Plan for Accelerated Recovery further stipulates that the District address ways to accelerate the recovery of areas impacted by phosphorus. Hydrologic restoration further aims to increase the areal extent of periphyton assemblages indicative of the natural system. Since periphyton respond rapidly to changes in environmental conditions (McCormick et al., 2002; Gaiser et al., 2004; Hagerthey et al., 2006; Hagerthey et al., in review) they are considered to be one of the most sensitive biological metrics in which to evaluate how management and restoration activities may affect the ecology of the Everglades. The objective of periphyton studies are to perform (1) detailed physiological and process based studies to develop a mechanistic understanding of the relationship between environmental conditions and elemental cycling within periphyton and (2) an ecosystem scale stoichiometric analysis to determine the major food web linkages in regions of the Everglades impacted by nutrients. The goal is to move beyond correlative studies towards the identification and isolation of factor(s) directly affecting periphyton structure and function.

Methodological Approach: Physiological and process based studies will address two fundamental questions. The first question addresses carbon, phosphorus, and nitrogen cycling within the periphyton complex. How does phosphorus influence autotrophic production and how are the products of primary production (carbon) used by heterotrophs within the periphyton complex? These studies will use a combined stable isotope enrichment and biomarker approach to follow the transformation and fate of carbon fixed by photoautotrophs through consumption by heterotrophs (Boschker and Middleburg, 2002; South Florida Ecosystems Report, 2007). The second question addresses major ion effects associated with canal water intrusions into the marsh. The aim is to isolate which of the ions that comprise salinity (calcium, sodium, potassium, magnesium, bicarbonate, chloride, and sulfate) account for the observed changes in periphyton structure (see Microbial and Soil Processes: Mineral Impacts on the Soft-Water Everglades)? Physiological studies will be coupled to larger food web studies to determine how consumers utilize periphyton. The food web studies are a component of the Cattail Habitat Improvement Project (see CHIP section). These studies utilize a stoichiometric approach to link photoautotrophic production to heterotrophic production. The mass of carbon, phosphorus, and nitrogen in each trophic level will be coupled to rates of production to develop elemental budgets and determine the efficiency in which elements are transferred between trophic levels.

Application of Results: Since periphyton responds rapidly to changes in environmental conditions (i.e., they are the first biota to change) they can be used to adaptively manage ecosystem resources and guide restoration efforts. The results of these studies will be used to help evaluate options for management and restoration of the Everglades. Cause and effect studies will aid in interpreting and predicting how specific management activities (e.g., nutrient loads, water depths, and water deliveries) will influence periphyton structure and function and how these changes will cascade through the food web.

Prey Availability in the Mangrove Transition Zone

Project Overview and Background: As a result of water management operations [e.g., Combined Structural and Operational Plan (CSOP) for C-111 and Modified Water Deliveries] and CERP projects, near shore areas such as the Everglades salinity transition zone (especially along the northern coast of Florida Bay) should experience pronounced changes in freshwater flow and salinity. Submerged aquatic vegetation (SAV) found in this region (such as widgeongrass, *Ruppia maritime,* and *Chara* spp.) is thought to be sensitive to these changes (SFWMD, 2006). The argument behind objectives to protect and restore transition zone SAV is that it serves an important function for the fauna (including seasonal and resident waterfowl and fish species) that feed in and inhabit the oligohaline ecotone (Davis et al., 2005). Work proposed below is focused on examining how habitat conditions (salinity and vegetation) affect the resident forage-base fish community, an important resource for valued predator species of wading birds, sport fish, and crocodilians. It is thus linked to several hypotheses in our plan, including those that describe connections between wading bird nest success and prey density/location (hypotheses 2 and 3), and the importance of seagrass as habitat for estuarine fishes (hypothesis 5).

Fish habitat in the Everglades ecotone includes both SAV and mangroves that are frequently found in close proximity and are thought to serve similar ecological functions. SAV and mangroves share a reputation as preferred habitats for fish, providing superior foraging and refuge opportunities (for smaller resident and transient fishes) compared to nearby unvegetated patches (Sheridan and Hays, 2003; Gillanders, 2006; Heck and Orth, 2006). Few studies, though, have actually evaluated the foraging and refuge functions of mangrove and SAV habitats as an interconnected unit (habitat mosaic) for the fish community. Key questions remain unanswered for species that inhabit areas containing both mangroves and SAV (Odum et al., 1982; Gillanders 2006; Stevenson et al., 2006). Is one habitat more important for the foraging and survival of given species? How does the structure and interconnectedness of these habitats facilitate these functions? Food web analyses suggest that SAV may serve a more important role than mangroves for supporting the consumer food web, likely because mangrove detritus is less bio-available than that for SAV (Marguillier et al., 1997; Sheridan and Hays, 2003; and Kieckbusch et al., 2004). It may be, however, that the structural protection of mangroves provides an important refuge for species that feed in SAV (especially when SAV cover is sparse or ephemeral). Where these habitats coincide their inhabitants may benefit by having both available to serve these functions.

Management and Restoration Objectives: Performance measures established by RECOVER and for the Florida Bay and Florida Keys Feasibility Study (FBFKFS) specifically target the spatial expansion of these transition zone SAV species into Florida Bay. Even prior to assessing whether CERP will have these effects, technical criteria used to establish the Florida Bay Minimum Flow and Level (MFL) rule (SFWMD, 2006) described this transition zone SAV habitat as a target valued ecosystem component (VEC). A peer review of the MFL document pointed towards a weakness in using this VEC with so little understood about fish-habitat relationships in the Everglades transition zone (Stevenson et al., 2006). A primary objective of the District's Florida Bay research program is to increase our understanding of mechanistic linkages of freshwater flow, salinity, habitat, and fauna in this critical zone. Other sections of this plan outline proposed studies of hydrology and habitat; this section emphasizes studies of habitat and fauna.

The following hypotheses will be tested for this project:

- Forage fish metrics (fish density, biomass, and species richness) are affected by hydrologic drivers (salinity and water level) and by the type and density of vegetative habitat (i.e., mangrove prop roots or SAV).
- Vegetative habitat structure and patch connectivity are positively correlated with food availability, fish growth, and/or refuge from predation for transition zone forage fish.

Methodological Approach: The District will employ a multi-phase approach of examining both long-term Audubon of Florida field datasets and conducting targeted experiments to help us better understand the mechanisms behind forage fish distribution and habitat structure in dominant vegetation types of the Everglades transition zone. Working with Audubon of Florida scientists, the District will first examine existing empirical data from the last 10-15 years of transition zone fish and SAV monitoring (conducted by Audubon). This work will include the following activities:

- Analyze relationships between forage fish metrics (fish density, biomass, and species richness) and habitat type and density (including mangrove, SAV, and non-vegetated habitat types).
- Identify groups of forage fish species whose densities correspond with given habitat types (for use in subsequent experiments).
- Include different climatic conditions and distinguish habitat influences on fish metrics from those caused by seasonality, salinity, and hydrologic conditions.

As a complement to field analyses, we intend to conduct a suite of mesocosm and field experiments aimed at examining specific mechanisms affecting forage fish habitat selection and the interaction of such factors. These experiments will examine forage fish habitat selection, feeding rate, and rates of predation as a function of vegetative habitat type and quality. Forage fish density will also be adjusted in many of the experiments to examine density-dependent effects on foraging, predation, and habitat selection. This is an important part of the study because forage fish species are subject to varying degrees of concentration as water levels fluctuate across a hydrologic cycle. Subsequent experiments in the field will examine how broadly results from small-scale mesocosms can be extrapolated to real world conditions.

Application of Results: Work on this topic is intended to fill gaps identified by Stevenson et al. (2006) and implement the monitoring and research specified in the Florida Bay MFL Prevention Strategy (SFWMD 2007). Results from this project will then be used to evaluate the adequacy of the current MFL rule and provide a basis for a mandated update (due in 2011) of the Florida Bay MFL rule, as specified in the 2006 rule. The proposed project will also address uncertainties specified in the CERP Monitoring and Assessment Plan (see hypotheses at the beginning of this section) and improve existing and future predictive models for operational evaluations (e.g., CSOP) and CERP projects. A key determination from this work will be if the transition zone SAV habitat has unique benefits to the fauna that cannot be provided by mangrove prop roots alone (i.e., strictly structural). This is important because while mangrove coverage has actually increased across the transition zone in recent decades (Ross et al., 2000), SAV habitat has declined (Davis et al., 2005). Making such linkages will improve existing predictive models (e.g., ALFISHES, Cline et al., 2005) and our understanding of how changing habitat quality may affect transition zone prey and the predators that depend on them (Gutierrez and Iribarne, 2004). Improved forecasting capability is important for the success of CERP, operational planning, and future improvements of the Florida Bay MFL rule.

Tracing the Historic use of Tree islands by Wading Birds

Project Overview and Background: High phosphorus concentrations on Everglades tree islands are hypothesized to originate from wading bird guano (Orem et al., 2002; Wetzel et al., 2005). The redistribution of P from the marsh to tree islands was recently hypothesized as a requirement for tree island growth and expansion as well as the maintenance of oligotrophic conditions in the adjacent marsh (Wetzel et al., 2005). Thus tree island restoration, a key performance measure of CERP, may be dependent on the appropriate nutrient regime and wading bird distribution. Preliminary evidence suggests that uric acid, which is excreted as a solid, is stable in Everglades's sediments. We therefore hypothesized that it may serve as a biomarker to indicate historical tree island use by bird populations (Sklar et al., 2007). Biomarkers are specific biochemicals that can be used to indicate biological processes, and in some cases structure.

Management and Restoration Objectives: The objective is to document the presence or absence of wading birds deep within the interior of the Everglades before drainage and human hydrologic interference, and evaluate historic wading bird distributions during periods of time when extensive coastal super-colonies were known to exist.

Methodological Approach: The future utility of this approach is dependent on both field research and laboratory testing. Field studies examining tree islands that are currently versus historically used by birds and compare those with the adjacent marsh that should not show a biomarker signature will be implemented. In the laboratory, other organic chemicals will be investigated as a means to assess wading bird use such that we are not dependent on uric acid alone.

Application of Results: At present our restoration goals for wading birds are based on the understanding that historical supercolonies were associated with the coastal zone, however our knowledge of wading bird distribution within the Everglades interior is limited. Assuming biomarkers are refined and validated, a subsequent system-wide historical assessment of bird distribution, with an estimate of their interior marsh as opposed to coastal distribution, will be conducted of tree islands both on the coast and within the interior marshes. This will then help to set spatial restoration targets with more realistic time domains.

MANAGING FOR ACCELERATED ECOSYSTEM RECOVERY

The replacement of historic ridge and slough macrophyte communities by dense, monospecific stands of *Typha domingensis* (cattail) across large expanses of the northern Everglades is one of the most obvious impacts on Everglades ecosystem structure caused by elevated phosphorus loading associated with agricultural discharge. The 2003 Long-Term Plan required SFWMD to undertake large-scale research into restoration options that may accelerate recovery of these nutrient enriched areas of the Everglades; the key emphasis being the elimination of the dense stands of cattail. Several management actions were considered, including binding of soil phosphorus via chemical amendments, moving the nutrient enriched soils by scraping, vegetation elimination by harvesting, herbicide application, cutting, prescribed fires, shading, crushing, and combinations of one or more techniques. Each approach was evaluated in terms of the ecological benefits that would be provided, financial cost and environmental risks. It was concluded that a "natural" approach, particularly the use of prescribed burns, represents the most ecologically and economically sound strategy. Two alternative approaches: The Cattail Habitat Improvement Project (CHIP) and The Fire Project, were peer reviewed and are currently being implemented. Specific details can be found in Miao and Carsteen (2006), and in Newman et al. (2006). In brief, CHIP uses herbicides and fire to create openings within dense cattail stands, enhancing landscape heterogeneity to mimic patterns observed in natural ridge and slough environments, and therefore, improve ecosystem structure and function. The Fire Project focuses on the use of repeated burns as a management tool to drive ecosystem state change by reducing the competitive advantage of cattail facilitating the re-establishment of historic species. Whether repeated fires results in changes in phosphorus sequestration and shifts in plant species or whether landscape openings can be sustained in the long-term are some of the questions that will be examined in the future. Ultimately, resource managers will use the information gained from these studies, in conjunction with additional small scale field and laboratory experiments for the following reasons:

- Determine if the ecological benefits resulting from "large scale" removal of cattails are desirable.
- Assess the effort and cost required to implement on a large-scale the options addressed by the CHIP and Fire Projects for accelerated recovery.
- Compare the cost-benefit tradeoffs between accelerated recovery options and natural recovery.

Implicit within the mandates for accelerated recovery experiments are hypotheses that guide the designs and methodological approaches for both the CHIP and Fire Projects, and these are presented in more detail below in their respective project discussions. As a way of introduction, there is only one guiding hypothesis from the CERP Monitoring and Assessment Plan that drives the overall approach for managing for accelerated recovery of impacted wetlands in the Everglades.

Hypothesis 6: Plant Community Dynamics along Elevation Gradients

This basic hypothesis states that the composition and distribution of plant communities along elevation gradients are determined by patterns of hydroperiod, water depth, nutrient dynamics and fire patterns throughout freshwater wetlands of the Greater Everglades. A better and more directly relevant hypothesis can be derived from the Long-Term Plan section of the amended EFA, where it is stated:

> *"At the present time there are no specific management activities that have been demonstrated to accelerate recovery at a large scale. In addition, there are some concerns that active management in impacted areas may exacerbate phosphorus movement, particularly if not carefully investigated prior to implementation. However, there is evidence from short-term studies that options may exist for accelerating recovery. An example of such an option would be the use of prescribed burns in previously impacted areas. Other options might include the application of herbicides and/or harvesting in previously impacted areas."*

As a result of this guidance from the Long-Term Plan we replace the above RECOVER hypothesis with a special Long-Term Plan hypothesis:

Long-Term Plan Hypothesis 1: External Disturbances are Essential to Restoring Structure and Function in Nutrient Enriched Areas of the Everglades.

Cattails, sawgrass, willows and water lilies all have different hydroperiods because they commonly grow at different elevations relative to mean water depths. This modification to hypothesis 6 is the basis for our belief that manipulation of hydrology, or nutrients, or fire, can have significant ecological consequences. To a large degree, we have already clearly demonstrated this affect when we conducted greenhouse, mesocosm, and field transect studies to establish the Total Phosphorus Threshold Rule for the Everglades (see the EFA). What has not been demonstrated is the time domain associated with any of these manipulations or the feedbacks from the plant community to the elevations. Thus, there are two corollaries that drive the CHIP and Fire Projects, respectively:

Corollary 1: Removal of densely vegetated community structure can affect food dynamics.

Corollary 2: Fire is the most rapid tool to alter plant community dynamics.

The Cattail Habitat Improvement Project (CHIP)

Project Overview and Background: While Everglades restoration as related to phosphorus has focused on reducing concentrations and loads to the region via the implementation of the stormwater treatment areas (STAs), a significant portion of the Everglades ecosystem remains impacted with high levels of phosphorus, readily evidenced by over 11,000 hectacres of monotypic *Typha* sp. stands. In 2003, the EFA was amended by the Long-Term Plan. In addition to further best management practices for agriculture (BMPs) and STA enhancements, the Long-Term Plan acknowledged that reduced surface water phosphorus concentrations and loads may not be sufficient to successfully restore highly enriched areas for decades. Consequently, the Long-Term Plan required SFWMD to undertake large-scale research into possible restoration options that may accelerate recovery.

Nutrient enrichment in the Everglades imposes constraints on ridge-and-slough communities through two pathways, food webs and vegetative structure. Nutrients have affected Everglades food webs directly by increasing plant nutrient content and productivity and by changing the species composition and biomass of periphyton, macrophyte, invertebrate, fish, and bird communities (Rader and Richardson, 1992; McCormick and O'Dell, 1996; Miao and Sklar, 1998; Turner et al., 1999; Crozier and Gawlik, 2002). The food web is also affected indirectly by the change in physical structure of the habitat brought about by the encroachment of uninterrupted stands of dense cattail. The dense structure of cattail stands affords relatively little incident solar radiation to the aquatic community, thereby moderating photosynthesis and primary production (Grimshaw et al., 1993). Little is known about how cattail structure affects the aquatic community, but at minimum it likely precludes populations of larger predatory fish species. Wading bird populations are also much reduced in cattail regions because foraging is constrained by dense vegetation (Bancroft et al., 2002; Hoffman et al., 1994; Crozier and Gawlik, 2002).

The Cattail Habitat Improvement Project (CHIP) was conceived in recognition that the recovery of key Everglades's characteristics may be accelerated through the creation of open-water patches embedded within the cattail matrix (**Figure 1**). Although removal of cattail will likely result in improved ecosystem structure, equally critical to environmental restoration is the return of some level of ecosystem function. CHIP will evaluate the utility of creating openings for improved ecosystem function by examining potential changes in trophic structure. A preliminary study using small-scale (10 × 10 m) open-water plots created in densely vegetated cattail stands demonstrated that the creation of open-water habitat results in increased dissolved oxygen (DO) levels, which in turn may cascade up trophic levels (Newman et al., unpublished data). CHIP is building upon this earlier study by establishing plots of sufficient size, such that all key ecosystem functional and structural components can be assessed. CHIP was peer reviewed and is currently in its second year of implementation. More specific details can be found in (Newman et al., 2006).

Management and Restoration Objectives: The Long-Term Plan required evaluation of approaches to accelerate the recovery of phosphorus-enriched areas of the Everglades. This resulted in considerable attention on removing cattail as a restoration method, despite the recognition that cattail removal is addressing the symptom as opposed to solving the problem. Large-scale intensive restoration efforts (e.g., peat removal or adding chemical amendments) will likely be more disruptive and harmful to the Everglades ecosystem than allowing the ecosystem to recover naturally. Additionally, large-scale cattail removal may be detrimental because the dense cattail areas adjacent to inflow points currently serve an important ecosystem function: protecting downstream pristine areas through their rapid growth and phosphorus removal. However, ecosystem function could be enhanced by recognizing the constraints inherent in a monotypic cattail community. That is, there may be some active management strategies that can be implemented in conjunction with a 'natural recovery strategy' that may improve ecological function, and thereby contribute to the overall intent of Everglades restoration. A key restraint is the density of the vegetation resulting in net heterotrophic production and limited access by wildlife. CHIP evaluates whether we can use active management, for example, a combination of fire followed by herbicide application, to maintain open water sites within densely vegetated areas to restore more desirable ecological function while external loads are addressed via STA and BMP implementation. The restoration objective is to create openings in the cattail landscape to bring about a critical change in ecosystem function such that the open system is dominated by algae or submerged aquatic vegetation and supports greater wildlife abundance and diversity.

Methodological Approach: CHIP will evaluate ecosystem function of the openings in two stages. The first objective is to assess whether creating openings within densely vegetated areas will sufficiently alter trophic dynamics such that wildlife diversity and abundance is increased. The experiment will consist of creating a 6.25 hectacre (ha) opening in a highly phosphorus-enriched landscape dominated by cattail and another 6.25 ha opening in a less-impacted transitional region comprising an equal mixture of cattail and sawgrass. Each created opening will be proximate to a paired control plot (untreated) and will be created using proven vegetation removal techniques. The experimental design is a 2 × 2 factorial with two treatments (created openings versus dense cattails/controls) and two locations (enriched and transitional), replicated three times. The second objective is to compare the opened plots with natural sloughs in

WCA-2A that are not affected by nutrient intrusion so the District can compare various changes in trophic structure to the natural Everglades. Ecological change will be measured using a relatively new approach, stoichiometry. This will result in a coupling of traditional methods of assessing the food web (e.g., species composition and abundance) with newer, technology-driven methods that quantitatively describe relationships between changing elements such as nutrient status and the elemental composition of various components of the ecosystem.

Objective 1 Hypothesis—Treatments plots (openings) will experience greater nutrient fluxes and be comprised of more nutritional plants (i.e., algae) and, therefore, lose higher percentages of production to herbivores (invertebrates and cyprinodontoid fish), channel lower percentages of primary production as detritus, experience faster decomposition rates and, as a result, store less carbon and nutrients, and support higher wading bird foraging.

Objective 2 Hypothesis—Relative to the phosphorus-limited Everglades, openings in phosphorus-enriched areas will experience greater nutrient fluxes and be comprised of more nutritional plants (i.e., algae) and, therefore, lose higher percentages of production to herbivores (invertebrates and cyprinodontoid fish), channel lower percentages of primary production as detritus, experience faster decomposition rates and, as a result, store less carbon and nutrients, and support higher wading bird foraging.

Preliminary results confirm that the burning of vegetation results in a change in phosphorus species in the soil and increased phosphorus in the overlying water column. In addition, areas in which openings are maintained are readily used by wading birds.

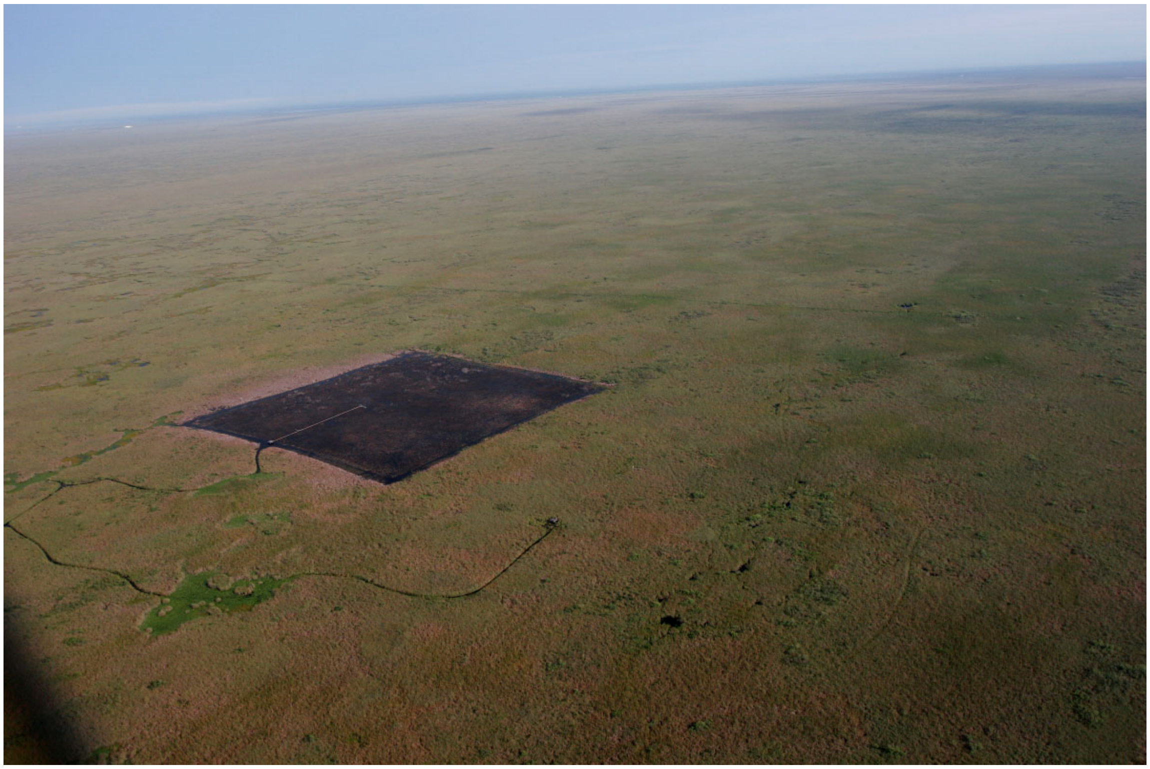

Figure 1. Aerial photo of a pair of CHIP plots in the transitional zone. The square to the left is the created opening, the trail to right of the open plots marks the beginning of the platform in the paired control plot.
Photograph, July 2007, J. Godin.

Application of Results: At the end a 3–4 year period, combining the results of objectives 1 and 2 will allow us to provide a preliminary assessment of the role of active management in accelerating the improvement of cattail habitat. This experiment will not provide recommendations on methods of cattail management, the size or locations of openings should they be determined to be a desirable option. If these open water areas are sustainable after the first three years, further studies (such as the interaction of vegetation mosaics) can be explored.

Ultimately, resource managers will use the information gained from this study, in conjunction with additional information from the Fire Project, and smaller-scale field and laboratory experiments, to: (1) determine if the ecological benefits resulting from "large scale" removal are desirable; (2) assess the effort and cost required to implement such options for accelerated recovery; and, (3) subsequently compare the cost-benefit tradeoffs between accelerated recovery and natural recovery.

Accelerated Cattail Removal: The Fire Project

Project Overview and Background: With improved water quality of flows entering the Everglades, natural recovery of impacted areas is expected; however, this process may take too long for the numerous stakeholders that feel the need to see dramatic improvements over relatively short time periods. Therefore, this project will look at repeated prescribed fires to control the spread and regrowth of cattail and possibly willow. Fire is a naturally reoccurring disturbance in the Everglades and is one of major driving forces that create and maintain the ridge-and-slough and tree-island landscape. Though prescribed fire has been used to actively manage cattail dominated communities in other areas of the Everglades, little has been reported on its ability to control willow and on the quantification of short- and long-term effects of fire on nutrient biogeochemistry in water, soil, and vegetation, or the shift in species composition in nutrient-enriched regions.

The Fire Project was recently initiated to assess whether repeated fire could be used as an effective cattail management tool to accelerate ecosystem recovery of the nutrient-enriched areas by hastening the re-establishment of sawgrass and other native species. In addition to cattail, willow (*Salix caroliniana*) stands; ranging from large patches encompassing hundreds square meters to small popcorn-like ones; have been increasing at alarming rates in the most nutrient-enriched portion of the Water Conservation Areas (WCAs), particularly in WCA-2A. Remote sensing satellite image analysis (Jensen et al., 1995) conducted between 1973 and 1991 reported the brush vegetation type (dominated primarily by coastal plain willow, *Salix caroliniana*) expanded at a rate equal to or greater than did cattails over the same period of time.

Several questions are being addressed by this cattail management project: (1) Will nutrients released by fire facilitate cattail expansion after fire? (2) Will nutrients released by fire be transported downstream? (3) Will fire stimulate sawgrass seed germination and seedling growth? and (4) When is the best time of the year to burn cattail? This field experiment was initiated using a Before-After Control-Impact Paired Series (BACIPS) experimental design to assess long-term ecological effects of multiple fires on the shift in vegetation dominance from cattail to native species and water and soil phosphorus biochemistry processes. This project is designed to document, and potentially distinguish, two types of recovery: natural and accelerating recovery at landscape level. This study will present the first large-scale ecosystem restoration experiment that is deliberately designed using BACIPS.

We hypothesize that natural and accelerated recovery that is driven by human manipulations such as fire, may follow similar long-term trajectories, but will progress at different rates. Accelerated recovery trajectories will reflect phosphorus pulsed events of diminishing magnitude following each subsequent fire. A single fire will release available phosphorus and facilitate cattail growth. However, multiple fires will provide a recurrent disturbance with a return interval that will accelerate the decline of cattail communities.

Management and Restoration Objectives: This project was primarily designed to assess (1) long-term ecological effects of multiple prescribed fires on critical wetland ecosystem processes, including phosphorus storage, cattail re-growth, and native vegetation recovery, and (2) natural recovery rates and patterns in the nutrient enriched areas after the implementation of BMPs and STAs without any further restoration attempts in the area. The information gained by the project will help resource managers to determine if repeated fire could be used as an effective management tool to accelerate ecosystem recovery of nutrient-enriched areas in the Everglades. Further, the project will contribute understanding fire ecology in the Everglades (and wetlands in general) and advance both design and analysis of large-scale and long-term ecosystem studies.

Methodological Approach: There are several hypotheses that will guide this research, (1) fire provides a stress for cattail, (2) nutrients that support cattail post-fire re-growth primarily come from internal storage, and (3) cattail post-fire re-growth will decline with multiple fires. To test these hypotheses, the District focuses on three main ecosystem processes and an ecosystem model, briefly described below:

Water quality: Wildfires or prescribed fires have the potential to release large amounts of nutrients and impact both soil and water quality. The amount of research conducted on fires and their impact on aquatic nutrient cycles, is limited and typically conducted on forested watersheds after a wildfire has occurred. In wetland systems, water quality responses may be one of the first ecosystem processes to respond to fire, however little is known about immediate and sustained fire effects on nutrient fluxes in surface and pore water, or whether nutrients released during fires will cause downstream effects on water, soil, and vegetation. The Fire Project monitors water quality changes at short (days to weeks) and long (months to years) time scales. The short-term water quality sampling is intended to capture the peak nutrient pulses right after the burn, whereas the long-term monitoring addresses whether these changes are sustained.

Soil chemistry: Soil biogeochemistry in wetland systems is an important link between surface water and vegetation. The main research questions for the soil processes include: Will soil nutrient concentration as well as availability be changed by fire? Will total phosphorus change in the bottom detritus, active sediment layer, or deep sediments? Will the relative contributions of inorganic and organic phosphorus change? And will bioavailable forms of phosphorus increase as a consequence of surface fire? Phosphorus flows and storages include feedbacks between macrophytes, water, and soil, as well as pulsed events resulting from fire. To answer these questions, soil nutrient concentrations, phosphorus availability, and soil redox potentials are measured at different depths.

Vegetation dynamics: Cattail recovery dynamics following a fire and the recruitment of other species are two critical components of the project. The main research questions are: What are the responses of the cattail community to fire? How much aboveground biomass and phosphorus will be removed after each fire? How can fire effect belowground phosphorus storage in cattail? How long before plant biomass returns to pre-burn levels; after one, two, or three fires? Will cattail regrowth rate decrease with each subsequent fire? And, will phosphorus storage in plants change with time since fire and number of fires? This project employs an ecosystem approach to investigate key vegetation processes including nutrient fluxes, cycling and storage, productivity, population dynamics, and species composition in response to fire, as well as feedbacks to soil and water. The vegetation processes are studied at the individual, population, and community levels both above- and belowground. These include seed germination, leaf growth dynamics, plant component nutrient concentration, root growth, plant density, and speciation as well as litter production and decomposition.

Tree Islands: The Fire and CHIP projects currently focus exclusively on the restoration of cattail-dominated habitats. Yet, in addition to cattail, willow (*Salix caroliniana*) stands; ranging from large patches encompassing hundreds square meters to small popcorn-like ones; have been increasing at alarming rates and will likely continue to expand. While large willow heads are extensively used by wildlife in other areas of the Everglades, for example Alley North in WCA-3A, the appropriate scale or plant species diversity to maximize the habitat use is not known. The future research of accelerating recover will assess several management and restoration approaches to various sizes of willow stands. The first focus will convert large willow stands to tree islands with several native Everglades tree species and be compared to large willow stands that are left as controls. The large willow stands, particularly those with slightly greater elevation in northern WCA-2A will be selected and be treated by fire or other methods to reduce its coverage and density in late fall. Native tree species will be introduced by seeding and/or transplanting to tree islands. Additional research will examine various approaches that are ecologically and environmentally sound to eradicate the popcorn-like willow stands. Restored willow stands will improve not only landscape diversity and ecosystem function, but also may accelerate nutrient sequestration in impacted areas as tree islands are hypothesized to have such function.

Modeling: Although this is a large-scale ecological experiment using a whole-ecosystem approach, the observed area is small compared to the areas under consideration for accelerated recovery. Controlling the experiment for all parameters and environments under question would simply not be possible. Predictive modeling efforts to scale up information obtained from the project are imperative. A process-based model will be developed to explore the spatial and temporal ecosystem effects of using prescribed burning for accelerating the recovery of nutrient enriched areas of the Everglades. The conceptual model consists of five modules: plant growth, plant competition, hydrology, nitrogen & phosphorus biogeochemical cycling and fire. The long-term goals for this modeling initiative are divided into four phases:

1. **Parameterize, calibrate and validate** the model output against the short-term experimental results of the prescribed fire in the highly enriched area.
2. **Fine-tune** the plant growth and competition modules to account for species interaction and plant community dynamics.
3. **Apply** the model to assess the natural recovery process (without prescribed fires), and to explore the recovery process under various different actively managed fire regimes.
4. **Develop** a user-friendly graphical interface that makes it a practical and usable wetland management tool for deciding when to burn, where to burn, how much to burn, and how often to burn.

Application of Results: Currently, there are no resources for managers and policy makers to access natural and accelerating recovery options in the nutrient enriched areas and to fully implement the Long-Term Plan. Since the process and timeframe involved in natural recovery is unknown, failure to implement accelerated recovery options may actually result in continued ecosystem degradation in the near future. The information gained by the project will help resource managers to determine if repeated fire could be used as an effective management tool to accelerate ecosystem recovery of nutrient-enriched areas in the Everglades. Further, the project will contribute to our understanding of fire ecology in the Everglades (and wetlands in general) and advance design and analysis of large-scale and long-term ecosystem studies.

Overall, the two ongoing large-scale ecosystem projects and the willow expansion study will address accelerated recovery in nutrient-enriched and cattail-dominated areas. Although these research efforts share the common objectives, they specifically address different management strategies. The Fire Project focuses on the use of repeated burns as a management tool to drive ecosystem state change by reducing the competitive advantage of cattail and facilitate re-establishment of historic species. The CHIP Project focuses on creating openings within the dense stands of *T. domingensis* to improve ecosystem function, whereas the willow study may provide opportunity for the tree islands in the area. Ultimately, the results from all these studies will be used to assess the potential to implement management actions geared towards accelerating recovery, as required by the Long-Term Plan.

UNDERSTANDING ECOSYSTEM PROCESSES

Both the Everglades ecosystem and the Florida Bay ecosystem, which is downstream and functionally linked to the Everglades, are strongly influenced by water management via biogeochemical processes. These processes include both material exchanges with the area outside of these ecosystems, such as nutrient loading via canals, and processes within these ecosystems, such as nutrient retention associated with soil accretion. Water management influences these processes not only via canal inputs and transport of materials with fresh water flow through the Everglades, but also via hydrologically mediated effects on microorganisms, plants, and animals. For example, organic matter decomposition and associated soil loss or accretion is affected by molecular oxygen availability, which is influenced by stage and hydroperiods. Likewise, Florida Bay processes are strongly influenced by salinity, which depends in part upon fresh water inputs from the Everglades.

Both the remnant Everglades and Florida Bay, 80 percent of which is in Everglades National Park, are part of the Everglades Protection Area (EPA). The primary focus of the EFA of 1994 was protection of the EPA from phosphorus enrichment. Thus, a primary and long-standing focus of District research has been the effect of phosphorus loading on the Everglades. The Everglades Division's EFA-mandated Phosphorus Threshold Research Program provided the empirical and experimental evidence that was the main basis for the 10 ppb standard that was recommended by the Florida Department of Environmental Protection (FDEP) in 2001 (Sklar et al., 2005). The Division's past research also included the Everglades Nutrient Removal (ENR) Project, which developed and tested prototype Stormwater Treatment Area (STA) design and performance, and became the basis for construction and operation of current STAs.

Since completion of the Phosphorus Threshold Research Program and ENR Project, the District has continued to monitor and research phosphorus distribution, transport, cycling, and effects in association with studies of plant community and landscape dynamics within the EPA, serving both the EFA and the District's Long-Term Plan for water quality compliance. Much of this research is focused on identifying management options for accelerating recovery of phosphorus impacted regions of the Everglades (see the *Accelerated Recovery* section of this appendix). Other research is focusing on understanding ecosystem processes that have historically created and sustained landscape features that have been lost from much of the Everglades and that are targets for protection and restoration (see the *Landscape* section of this appendix).

In this section, prospectuses of two sets of research projects are presented: (1) Everglades microbial and soil processes; and (2) the functional relationship of Florida Bay and its Everglades watershed. Both of these sets utilize numerical modeling as tools for information synthesis, increasing mechanistic understanding, and forecasting responses to water management. The first set of projects includes a model of soil processes associated with accretion and development of soil biomarkers related to decomposition processes. Knowledge of soil dynamics is critical for restoration of Everglades landscape features (such as ridge-and-slough), responses of coastal wetlands to the combination of water management and sea level rise, and understanding nutrient retention and release in relation to water quality and patterns of primary productivity. The first set of projects also includes research, complementary of phosphorus-effect studies, on the effects of non-phosphorus mineral enrichment from canals on periphyton. Intrusion of water with high ionic concentrations into the Everglades appears to alter periphyton structure and productivity and thus potentially can cause an "imbalance" in the ecosystem (the narrative standard of the EFA).

The second set of proposed projects describes how the District will integrate monitoring, research, and modeling to understand the functional linkage of Florida Bay and the Everglades. Understanding and building a predictive capability regarding the influence of water management on Florida Bay requires understanding the relationship of fresh water flow with: (1) salinity magnitude, spatial and temporal variability; (2) estuarine hydrodynamics (especially water residence time); (3) supply of nutrients and other materials (especially nitrogen and phosphorus loading) and resultant water quality (especially algal blooms); and (4) the structure and productivity of SAV habitat and associated fauna (especially regarding fisheries).

Understanding the Everglades-Florida Bay linkages are essential for water management operational planning, Minimum Flows and Levels, EFA compliance, and ecosystem restoration. In particular, the Florida Bay MFL rule, accepted by the District and FDEP in 2006, specified that District "continue field monitoring and research to assess salinity, water level and flow conditions and biological resources response in the region…" and that a Prevention Strategy would be incorporated into the Lower East Coast (LEC) Water Supply Plan. The 2005–2006 LEC Water Supply Plan Update (SFWMD, 2007) includes this prevention strategy for the Florida Bay MFL. This strategy is the implementation of ongoing efforts to protect Florida Bay [especially the Combined Structural and Operational Plan for the C-111 Project and Modified Water Deliveries to ENP (CSOP), the C-111 Spreader Project, and CERP's Florida Bay and Florida Keys Feasibility Study] and for continued hydrologic and ecological monitoring, research and modeling to assess and understand the Florida Bay ecosystem, assess the validity of the adopted MFL criteria to prevent significant harm and improve the scientific basis for any future revision of the criteria. Much of the research specified in this appendix was based on the 2005 peer review (Stevenson et al., 2006) of the Florida Bay MFL Technical Documentation Report (Hunt et al., 2006).

Primary RECOVER Hypotheses that will be in addressed, in part, by the projects described in this section are:

Hypothesis 7: Nutrient Inputs and Sheetflow as Determinants of Wetland Nutrient State in the Everglades.

The dominance of direct rainfall as the primary source of water and phosphorus, in combination with sheetflow and related hydrologic and climatic characteristics, resulted in an oligotrophic, phosphorus-limited nutrient state throughout the greater Everglades wetlands prior to drainage.

Hypothesis 8: Everglades Ridge-and-Slough Microtopography and Landscape Pattern in Relation to Organic Soil Accretion and Loss.

Sheet flow interacts with hydroperiod, water depth, fire, and nutrient dynamics to maintain organic soil accretion and loss in a state of dynamic equilibrium. Degradation of microtopography interacts with hydroperiod, water depth, eutrophication, fire, and exotic plants to reduce the diversity and stability of habitats which were previously long-term, large-scale features of the ridge and slough landscape.

Hypothesis 9: Sea Level and Freshwater Flow as Determinants of Coastal Transgression.

Sustained substrate buildup by physical and biological processes in many coastal marl and mangrove environments of south Florida will not be capable of keeping up with rates of sea-level rise during the 21st Century. Where rates of peat or marl elevation buildup do not keep up with rates of sea level rise, shoreline transgression and landward salinity intrusion into mangrove and freshwater wetlands will occur.

Hypothesis 10: Sea Level and Freshwater Flow as Determinants of Production, Organic Soil Accretion, and Resilience of Coastal Mangrove Forests.

Production and organic soil accretion in the mangrove forests of the coastal Everglades are controlled by phosphorus availability, with relatively high inputs from marine sources and low inputs from freshwater sources. Phosphorus availability, mangrove production, and soil elevation are thus driven by the opposing influences of sea level and sheet flow from the Everglades. Resilience of the mangrove forests of the coastal Everglades after disturbance is dependent on hydrologic flushing by either fresh or saline water, which is driven by sea level and sheetflow from the Everglades. Resilience also varies with soil fertility.

Hypothesis 11: Florida Bay Water Quality Hypotheses

a) Through modifications of quantity, quality, timing, and distribution of freshwater, CERP implementation will affect dissolved and particulate nutrients delivered to estuaries and alter estuarine water quality. These modifications will affect primary production and food webs in estuaries. This includes:

- Modified nutrient distribution and timing via changes in Shark River Slough flow and diversion of canal flows from point source to more diffuse delivery through coastal wetlands and creeks;
- Modified nutrient quantity by source controls (e.g., treatment area uptake) and by changes in nutrient processing and retention in the Everglades;
- Modified bioavailability of nutrients via changes in the composition of dissolved organic matter (DOM) from the watershed and internal estuarine mechanisms (e.g., phosphorus limitation of DOM decomposition).

b) Internal biogeochemical process rates (e.g., denitrification and phosphate sorption on carbonate mud) will change with CERP implementation because of salinity and benthic habitat changes.

c) Nutrient accumulation and retention in estuaries is affected by episodic storm events that can export sediments. CERP implementation will modify benthic habitats and nutrient loading, which will affect this export.

d) The spatial extent, duration, and composition of phytoplankton blooms are controlled by several factors that will be influenced by CERP, including: external nutrient loading, internal nutrient cycling, light availability, water residence time, and grazers.

e) Nutrient inputs from groundwater discharges may affect water quality in coastal wetlands and estuaries. CERP implementation will modify these discharges in the coastal zone, which will alter nutrient loads to the estuaries.

Hypothesis 12: Florida Bay Submersed Aquatic Vegetation Hypotheses

a) Changes in both salinity and water quality from CERP implementation are expected to result in changes in seagrass cover, biomass, distribution, species composition and diversity through the combined and interrelated effects of light penetration, epiphyte load, nutrient availability, salinity, hypoxia/anoxia, sulfide toxicity and disease.

b) Changes related to CERP implementation will include an expansion of areas with *Halodule* and *Ruppia* cover and a reduction in areas of *Thalassia* monoculture along the northern third of Florida Bay. Based on forecasted changes in hydrology, seagrass density and species composition in the rest of the Bay are not expected to change.

c) Significant changes in benthic algae and seagrass distribution and density can affect sediment suspension and stability of mud-banks, as well as nutrient availability to other primary producers.

MICROBIAL AND SOIL PROCESSES

Wetland ecosystem processes responsible for maintaining the dynamic equilibrium between soil accretion and soil subsidence, such as primary productivity and decomposition, are thought to be critical to the preservation and possible restoration of the tree island, slough, and ridge microtopography (Ogden, 2005). This microtopography, relative to mean water levels, sets the hydroperiods and depths that are experienced by the flora and fauna in a region. The ecological controls and the impacts of water management on microtopography are poorly understood and yet are critical to understanding why ridge vegetation is replacing both slough and tree island communities in the Everglades.

The dynamic equilibrium of the vegetation mosaic in relation to elevation gradients is maintained if biogeochemical processes in the soil support the physiological requirements of the vegetation. The dynamic equilibrium is altered if water depths or hydroperiods decline or increase. Anthropogenic disturbances of hydroperiods, water depths, eutrophication, fire patterns, and the spread of exotic plants and animals have shifted the vegetation mosaic away from the historic dynamic equilibrium. Vegetation gradients between higher elevation ridges and tree islands and lower elevation slough communities are of particular concern in the Everglades. A potential trade-off exists between slough habitat restoration and the extent and quality of adjacent tree islands. These microbial and soil studies are designed to focus experimental, synoptic and modeling approaches on the issues of habitat loss, vegetation shifts and ecotone boundary changes.

Modeling Soil Dynamics

Project Overview and Background: Ecosystems are considered “stable” if the state variables and processes of interest (e.g., vegetation, productivity, and nutrient cycling) return to more or less the same state after a disturbance (DeAngelis and Waterhouse, 1987). In wetlands systems, stability is critically linked to a wetland’s ability to accrete soil (or erode) and maintain hydrologic conditions suitable for plant productivity (Mitsch and Gosselink, 2003). In coastal marshes, for instance, accretion rates and thus surface elevation must keep pace with rising sea-levels. When sea-level rise outpaces accretion, a resilience threshold may be exceeded, leading to loss of wetland habitat (Kearney et al., 1988; Reyes et al., 2000; Lane et al., 2006). Other disturbances, such as widespread plant mortality or soil overdrainage, can lead to peat loss and more open, eroded systems, with novel community structure and ecosystem function (Cahoon et al., 2003).

In the Everglades, accretion plays a key role in the stability of tree islands and ridge-and-slough microtopography (SCT, 2003). A conceptual model, presented in **Figure 2**, highlights various ecosystem functions that alter accretion (**Figure 2**) and feedback loops by which changes in accretion are hypothesized to create stable states in Everglades communities (**Figure 2**). Tree island stability, for instance, is hypothesized to be maintained by high accretion rates, which maintain drier soil conditions and favor woody plants with high evapotranspiration (ET) rates. High ET rates pull in and concentrate nutrients from surrounding marsh porewaters, thus reinforcing high rates of productivity and accretion (Wetzel et al., 2005; Ross et al., 2006).

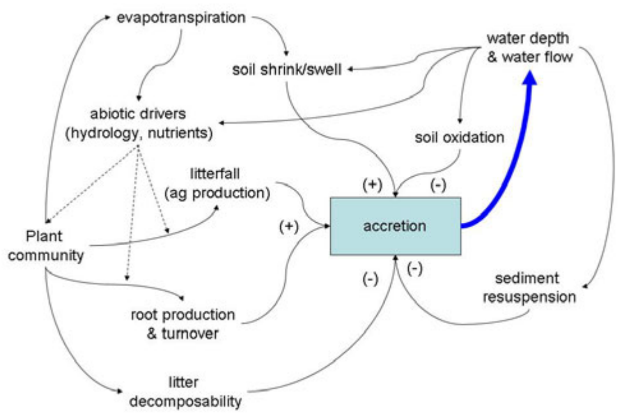

Figure 2. Conceptual model of ecosystem functions affecting soil accretion. This model allows for tree island development, in which the feedback of accretion on hydrology (blue arrow) causes changes in plant community, evapotranspiration and nutrient cycling (Wetzel et al., 2005). This model also allows for ridge-and-slough microtopography development, where the feedback of accretion on hydrology causes changes in plant community, litter decomposition and accretion/erosion (SCT, 2003; Larsen et al., 2007).

To develop a complete understanding of accretion is complicated, however, because the effects of altered accretion rates are resolved over many years or decades, making it difficult to test hypotheses with short-term experiments. To bridge this temporal gap, models can integrate empirical observations and lead to an understanding of the implications of accretion on long-term dynamics (e.g., Rybczyk et al., 1998; Nungesser et al., 2003). More recently, accretion models have included the use of paleoecological data to provide driving variables that allow models to hindcast long-term (multi-century) marsh vegetation change (Saunders, 2003). In addition, paleoecological profiles of macrofossils, stable carbon isotopic signatures and species-specific biomarkers provide validation data for the long-term plant and soil dynamics simulated by accretion models (Saunders, 2003; Saunders et al., 2007).

This project will use a modeling approach to assess the degree to which historic changes in sheetflow underlie currently degraded vegetation and soil conditions (e.g., disappearance of deep sloughs in ENP; loss of ridge-and-slough microtopography in general), the timing of those responses, and management strategies for sheetflow and nutrient inputs required for successful restoration (RECOVER Hypotheses 7 and 8). A subsequent application of this work will quantify the pace and magnitude of sea-level induce changes in the sawgrass/mangrove ecotone and the degree to which accretion/erosion responses reinforce or buffer those changes (RECOVER Hypothesis 9).

Specific Management and Restoration Objectives: The integrative empirical and modeling approach described here will provide a tool for understanding how Everglades plant communities and soils will respond to hydrologic restoration measures over time periods that are relevant to ecosystem restoration. The goal of this work is to generate a quantitative framework for understanding Everglades ecosystem responses to altered hydrology, including (1) the effects of past climate variability and water management on system stability, and (2) effects of future hydrologic changes (e.g., restoration effects and natural climate variability) on system stability.

Specific objectives of this work are:

- To quantify the extent to which peat accretion in tree islands (and long-term stability) is affected by changes in water depths, water flow and sediment transport.
- To quantify the extent to which peat accretion in ridges and sloughs, and the consequential effects on their micro-topographic differences, is affected by changes in water depths, water flow and sediment transport.
- To identify the ecosystem processes (for example: plant productivity-hydrology relationships, litter quality effects on decomposition, soil oxidation/compaction rates) that are most sensitive to hydrologic drivers and can be used to provide an understanding of the long-term accretion and stability of Everglades wetlands.

Methods and Procedures: This one-dimensional (1-D) accretion model structure and assumptions draw on previous examples from other wetland systems (e.g., Morris and Bowden, 1986; Callaway, 1994; Rybczyk et al., 1998; Day et al., 1999; Nungesser et al., 2003; Saunders, 2003). Main components of this model includes above and belowground production of competing plant species, litter quality and abiotic (including hydrologic) controls of soil organic matter (SOM) decomposition, sediment deposition/erosion, soil compaction, fluctuating hydrology (mainly water depths) and the interrelationships among these processes. This model will be designed to simulate accretion rates, elevation changes and soil profile changes in organic matter and mineral matter, along with paleoecological proxies specific to Everglades systems (Saunders et al., 2006; Chmura et al., 2006) over decades to centuries.

This research integrates a variety of data used for calibration, validation, and system drivers (**Figure 3**). System driving variables, mainly hydrologic variables governing water depth and water flow, comprise the DRIVERS data set. The PROCESS data set includes the results of field and mesocosm/greenhouse studies and data from the published literature quantifying key ecosystem processes (e.g., plant productivity, litter decomposition, seed production and relationships with abiotic covariates). These data are used mainly for calibration purposes. The PALEO data set includes results from the analysis of soil profiles related to organic constituents (e.g., labile/soluble fractions and more recalcitrant cellulosic material and lignins), inorganic constituents (e.g., nutrients and $CaCO_3$ content, total ash-dry weight), radiometric soil dates (e.g., ^{210}Pb and ^{14}C dates), and paleoecological proxies such as fossil seeds and biomarkers. PALEO data are used for both calibration (especially for parameters that cannot be directly measured) and for validation (testing model predictions of soil accumulation and accretion from soil constituents and radiometric dates and vegetation dynamics from macrofossil and biomarker profiles).

Sediment Erosion Table (SET) data include repeated measurements of sediment elevation and accretion using a SET developed by Boumans and Day (1993) and Cahoon et al. (2002a, b). These data will be used to test model simulations of elevation and accretion over shorter time-scales (several months to several years). Forthcoming SET research will include *in situ* measurements in tree island and ridge-and-slough communities and measurements at the Loxahatchee Impoundment Landscape Assessment (LILA) experimental site. LILA will provide a unique setting for applying an experimental approach to refine model assumptions and equations governing accretion and elevation and refine their relations to ecosystem processes (e.g., water flow, water depths, primary production, floc transport, decomposition).

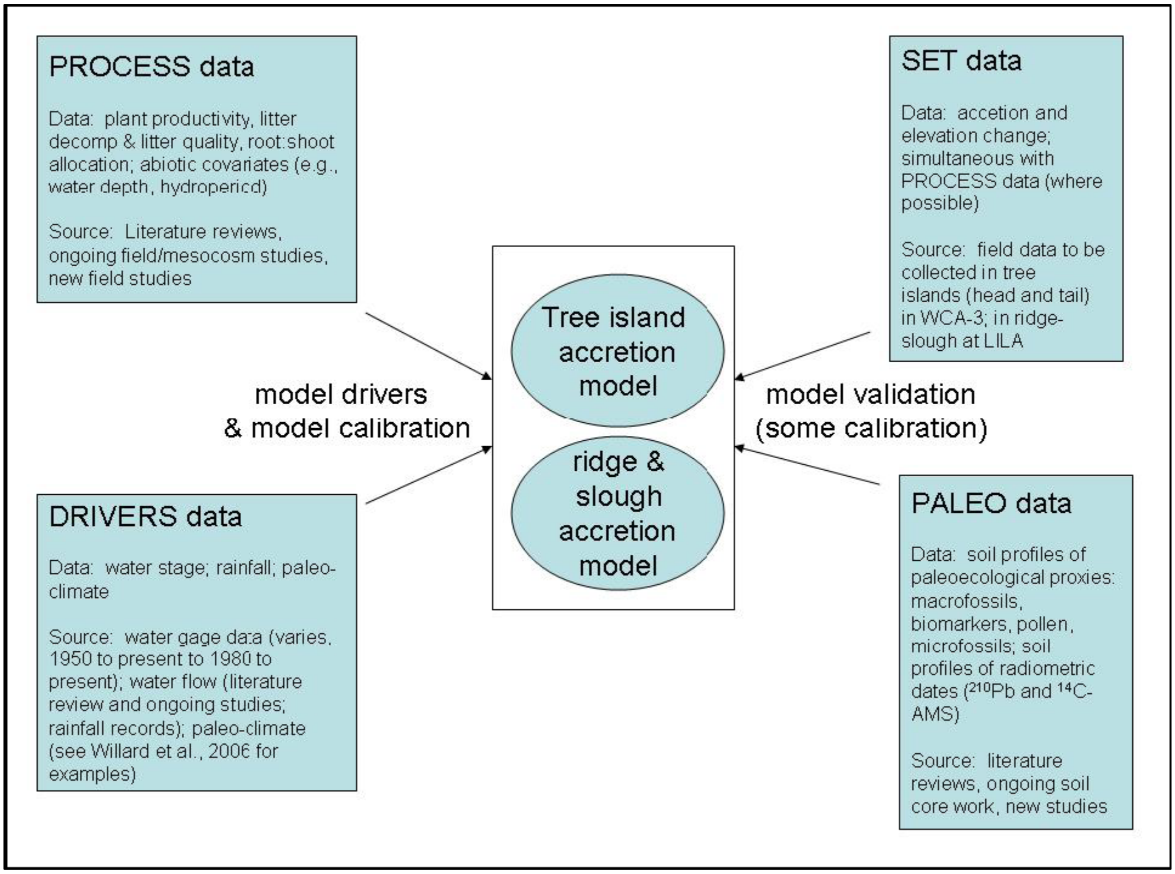

Figure 3. A summary of the four data sets integrated with accretion models.

Application of Results: These objectives will quantify the thresholds in water depths/hydroperiods and water flow that promote or reduce the stability of tree islands, ridge and slough vegetation (relative to historic levels), and ridge-and-slough microtopography (relative to historic microtopography). For instance, one application of the model may be to evaluate the degree to which floc transport and deposition observed from short-term (days to months) adaptive management experiments (e.g., DECOMP Physical Model and LILA experiments, **Figures 6** and **7**) result in more or less system stability when simulated over years to decades. In addition, model sensitivity analyses will help identify ecosystem processes that regulate those thresholds and which of these processes should be research priorities aimed at assessing restoration success.

The soil accretion model developed here is a general ecosystem process model that can also be applied to other areas and issues in the Everglades. While our initial focus is on freshwater habitats, a forthcoming collaborative project (funded externally through CESI/DOI) involving researchers at SFWMD, the Florida Coastal Everglades LTER, FIU and ENP will begin applying this framework for understanding coastal wetlands responses to hydrologic restoration and rising sea levels. Necessary modifications to the conceptual model in **Figure 2** include relationships by which salinity and flooding regimes alter primary production (in sawgrass, mangrove and open water habitats), and decomposition, with consequent changes in soil accretion and accretion-mediated feedbacks. Despite these modifications, the framework will continue utilizing the same four principal data sets (**Figure 3**) which are available from published literature (e.g., PALEO data in Willard et al., 2001; DRIVERS data from sea-level records and paleo-reconstructions of sea level) and ongoing studies (e.g., PROCESS and SET data through FCE LTER and SFWMD research programs). An anticipated application of this work will be to quantify the pace and magnitude of ecotone changes in sawgrass, mangrove, and/or open water habitats and the degree to which accretion/erosion responses reinforce or buffer those changes.

Microbial Biomarkers and Decomposition

Project Overview and Background: In the Everglades landscape, the microbial community, both structure and to some extent function, has received limited study. Understanding the change in characteristics and process rates of the microbial community on key functions such as peat accumulation and nutrient turnover are essential to ensure successful restoration. A key objective required by the Long-Term Plan is to accelerate the recovery of nutrient-impacted areas. Previous studies demonstrated that phosphorus enrichment results in increased nutrient turnover through increased decomposition of plant litter and soil mineralization (e.g., Newman et al., 2001). However, the District does not understand the converse—how communities and functions change as phosphorus loads are reduced—and, then, how the District can manage the ecosystem to optimize microbial binding and minimize the downstream transport of phosphorus. Similarly, peat loss is a fundamental change the ecosystem has experienced in response to overdrainage. Peat accumulation is a result of the differential between plant production and decomposition, with the activity of the microbial community being the rate-limiting step. Thus, it is important to characterize and quantify the changes that occur in the microbial community in response to changes in hydrology.

Management and Restoration Objectives: Understanding how water management and restoration activities (e.g., phosphorus reductions and hydrologic restoration) impact the ecology of Everglades is best captured by microbial processes as they respond rapidly to changes in environmental conditions. Microbial processes (e.g., decomposition and nutrient turnover) can influence larger-scale ecosystem processes such as peat accretion and food web dynamics. Microbial process studies while powerful are limited because they are restricted to only one component of the microbial community, which can be comprised of a complex association of bacteria, algae, and fungi. The District aims to utilize phospholipid fatty acid (PLFA) methods to rapidly assess the microbial composition and biomass of soil, floc, and periphyton. Such simple information may prove incredible useful, especially when linked with process-based studies, to ascertain water management impacts or if desired restoration targets are being achieved.

Methodological Approach: Phospholipid fatty acids (PLFAs) provide a rapid means to characterize the major functional microbial components of the ecosystem that the District knows little about. Unique PLFA biomarkers have been identified for gram negative bacteria, gram positive bacteria, algae, fungi, actinomycetes, sulfate reducers, and methanotrophs (Boschker and Middleburg, 2002). These biomarkers can be used to determine not only the structure of the microbial community in periphyton, floc, and soils but also to estimate the biomass of each group. The ability to rapidly characterize and quantify the microbial community is critical to link structural and functional components. For example, PLFA-derived microbial composition and biomass estimates can be linked with enzyme degradation measurements to assess decomposition and nutrient turnover.

PLFA analysis will be used to characterize the soil, floc, and periphyton microbial communities among experimental treatments associated with the CHIP project. Briefly, treatments include unenriched sloughs, phosphorus-enriched plots of very dense cattail, phosphorus-enriched areas of cattail and sawgrass, and adjacent plots in which the vegetation was removed. PLFA samples will be extracted, purified, and derivatized from lyophilized floc, soil, and periphyton samples by the one-phase extraction procedure of (White et al., 1979) modification of the Bligh and Dyer method. Microbial composition and biomass will be coupled with the numerous processes being measured within CHIP.

Application of Results: This approach will initially be assessed as part of our Accelerated Recovery efforts (see CHIP project description in this appendix), which will test its potential application in ridge-and-slough formation and tree island development. Similarly, studies suggest that invasive species may modify the environment by altering the microbial community (Kourtev et al., 2002), thus a comparison of structure and functional aspects of the soil microbial community may lead towards alternative management strategies for invasive species.

Mineral Impacts on the Soft-Water Everglades

Project Overview and Background: Anthropogenic loading of phosphorus, has by far, been the most studied nutrient response in the Everglades. There is increasing evidence, however, that the landscape is also influenced by the chemistry of the bedrock. Historically, the northern Everglades was a soft-water, peat ecosystem with a periphyton assemblage dominated by acidophilic diatoms and desmids. The building of canals and pumps to manage water in South Florida has led to the intrusion of hard-water into the WCAs. The periphyton composition in phosphorus-limited areas of WCA-2A and WCA-3A have shifted to calcium carbonate mats dominated by filamentous cyanobacteria and soil accretion has changed from a peat accumulating environment, to one with both organic soil and marl accumulation. However, softwater periphyton assemblages are still present in regions of WCA-3A and the Loxahatchee National Wildlife Refuge (LNWR), distant from current discharge points and canals.

A small scale laboratory study, combined with analysis of long-term transect data, suggests that the softwater periphyton assemblage is lost when specific conductivity is greater that 350 µS/cm (Hagerthey et al., in prep). However, the mechanism or specific element that causes this loss is unknown. Nor is it known whether this switch from a softwater to hardwater ecosystem is reversible.

Management and Restoration Objectives: Water quality remains a concern for the management and restoration of the Everglades. While the EFA specifically required the numeric interpretation of phosphorus levels that caused change, the requirement of no imbalance in natural flora and fauna extends beyond the effects of phosphorus to include any element. The objective of this research is to examine the ecological effects of the introduction of mineral enriched water into the Everglades. The scope of this research focuses on the major cations (calcium, sodium, potassium, magnesium) and anions (chloride, sulfate, and carbonate species). Current Everglades restoration efforts have a stronger emphasis on water quantity, timing and distribution. However, it is important when addressing hydrologic restoration that the District is aware of the potential tradeoffs with water quality.

Methodological Approach: A similar approach to that used in the phosphorus threshold program will be used to examine the ecological affects of hard-water intrusions. Experiments will be conducted across multiple scales to provide a comprehensive picture from which to derive water management and restoration strategies. These studies will range from small mechanistic laboratory studies to large scale field investigations. For example, small laboratory scale and mesocosm field studies aimed at elucidating the mechanisms controlling periphyton species loss, along with understanding the ecological importance of such a shift. Large-scale field studies will be used to optimize water management to minimize the ecological impact of canal water intrusion events.

Application of Results: The multiple-scale approach will enable water managers and scientists to develop strategies that minimize the impacts of increasing the water hardness of the Everglades. Both CERP and future operations of STA-1W and 1E, have the potential to cause further intrusion of hard-water into soft-water portions of the Everglades, particularly LNWR.

FLORIDA BAY—EVERGLADES LINKAGE

Understanding and forecasting the influence of water management on the character and dynamics of Florida Bay requires a large-scale, integrative approach. This challenge entails understanding the functional linkage of two large and complex systems—the Everglades wetland and the Bay itself. Furthermore, the Bay is strongly influenced by interactions with the Gulf of Mexico, the Florida Keys, and the Atlantic Ocean. The District has implemented a program of monitoring, research and modeling to meet this challenge (see *2008 SFER – Volume I*, Chapter 12 for summary of progress from this program). Numerical models have a central role in our strategy to understand complex systems, providing a mechanism for information synthesis, hypothesis specification and testing, and forecasting (Hobbie et al., 2000). The District is developing a suite of large-scale dynamic models in order to build a sound basis for water management decisions for the purposes of Bay restoration and evaluating tradeoffs associated with large scale water distribution decisions (such as the relative ecological costs and benefits of distribution to Biscayne Bay versus Florida Bay via Taylor Slough versus toward the Gulf of Mexico estuaries via Shark River Slough). Model development is largely being done through CERP's Florida Bay and Florida Keys Feasibility Study (FBFKFS), with scientific leadership provided by the Everglades Division. Our modeling strategy conforms with the Interagency Florida Bay Program's Strategic Plan (PMC, 2004) call for information synthesis via modeling and long-standing recommendations of several peer review panels convened specifically to guide and review this Program (Hobbie et al., 2006) and the FBFKFS. It is important to note that while the District is leading this ambitious synthesis, success depends upon cooperative monitoring, research, and modeling efforts with partner agencies and institutions, particularly the USGS, NOAA, ENP, and the Florida Coastal Everglades LTER (see Hunt and Nuttle, 2007, for recent programmatic synthesis).

Primary objectives for stewardship and restoration of Florida Bay are focused on the restoration of more natural and historical quantities, timing, and distribution of fresh water inflow to the estuary that will prevent harm to the existing system and allow restoration of biological communities. Specific targets for the restoration of the Bay include the redevelopment of extensive mixed-species meadows of seagrasses and enhanced forage fish base to support both wading birds and sport fish species. A key constraint is that changing fresh water flow must not degrade water quality and thus impair the Bay or Florida Keys' coral reef.

A model suite that will address these objectives will include watershed models, an ocean boundary hydrodynamic model, bay hydrodynamic and water quality models, and bay biological models. Watershed models include USGS' TIME (Tides and Inflows in the Mangrove Ecotone) wetland hydrologic model (with FBFKFS funding; based on Swain, 1999) to estimate fresh water inflow and mangrove zone models to estimate nutrient inputs to the Bay (see Mangrove Transition Zone section; statistical and process models such as Chen and Twilley, 1998). The HYCOM (Hybrid Coordinate Ocean Model) oceanic hydrodynamic model will provide ocean boundary conditions (Kourfalou et al., 2006). The EFDC (Environmental Fluid Dynamics Code) is an integrated hydrodynamic and water quality model that is at the heart of this model suite. This model is currently being adapted to Florida Bay for the FBFKFS (Hamrick, 2006). The District plans to incorporate the main components of our Florida Bay seagrass community model (see below; and Madden and McDonald, 2006) into an EFDC module, as well as improve current

EFDC biogeochemical processes including nutrient uptake and transformation, nutrient sequestration and primary production. This model, in direct or indirect integration with several other ecological models (including higher trophic level models for critical species, such as pink shrimp), will synthesize much of the knowledge base and data input concerning the Florida Bay ecosystem and will provide understanding of the ecosystem response to changes in inputs and water flow, estimating the effects of changing water management and distinguishing these effects from other forces.

Florida Bay Algal Blooms

Project Overview and Background: The structure and function of both the Everglades and Florida Bay, which are physically and ecologically linked, are strongly influenced by fresh water flow. A major component of this influence involves the hydrologic modification of nutrient availability via: (1) changes in external nutrient loading, transport, and export; and (2) effects on internal nutrient cycling. Ongoing projects, such as the C-111 Project and CERP projects (especially the C-111 Spreader and Decompartmentalization), that are modifying water management structures and operations for the purposes of environmental protection and restoration commonly focus on direct hydrologic targets and ecological targets that are strongly influenced by hydrologic conditions. However, such changes also influence biogeochemical processes (including primary and secondary productivity) and water quality. For Florida Bay, a major concern regarding Everglades restoration is that increasing fresh water flow will also increase nutrient loading and consequently increase the frequency, extent, and magnitude of algal blooms (Brand, 2002). This issue has received considerable attention (National Research Council, 2002) and is one of the critical uncertainties identified for CERP in the RECOVER Monitoring and Assessment Plan and the associated ecological conceptual model of Florida Bay (Rudnick et al., 2005).

Understanding the effects of changing fresh water flow on Florida Bay water quality, particularly regarding the occurrence of phytoplankton blooms, also requires: (1) estimation of nutrient loading to the southern wetlands from canals; (2) understanding how changing flow affects nutrient (both nitrogen and phosphorus) transformation, retention, and transport through the southern marshes (especially saline marshes) to the Bay; and (3) understanding of nutrient cycling within the Bay (see Rudnick et al., 2005, for a more extensive discussion). Changing flow and salinity can directly and indirectly affect nutrient availability and blooms. Salinity can directly affect phosphorus availability via ionic strength effects on phosphorus sorption and desorption on carbonate particles (the primary component of Florida Bay muds) (DeKanel and Morse, 1978). Changes in seagrass community structure driven by changing salinity may also have a strong effect on the availability of nutrients within the water column. The occurrence of algal blooms in Florida Bay has commonly been linked to seagrass die-off events, both as consequence of die-off and a cause of die-off (Zieman et al., 1999; Rudnick et al., 2005; Rudnick et al., 2007).

Management and Restoration Objectives: Water quality can be a major constraint on the success of restoration and other water management efforts. With regard to Florida Bay water quality, the primary objective is for water management to do no harm to Florida Bay. Algal blooms can cause such harm via the shading of seagrass beds and potentially causing sponge mortality (Dennison et al., 1993; Butler et al., 1995). Restoration performance measures (RECOVER and Florida Bay and Florida Keys Feasibility Study) include nutrient loading and chlorophyll-*a* concentration targets that would be associated with minimal phytoplankton bloom activity and sufficient light for sustainable seagrass communities. The objective of the monitoring, research, and modeling proposed in this appendix would provide a basis for quantifying the status and trends of nutrient inputs to the Bay and water quality conditions within the Bay, understanding the relationship of these inputs and conditions with freshwater flow, and providing a capability to forecast the water quality consequences of alternative water management plans.

Methodological Approach: Meeting the objectives above requires a combination of approaches, including monitoring, measurement of nutrient fluxes from multiple sources, experiments on factors influencing nutrient availability, and synthesis and quantitative analysis through modeling. Long-term hydrologic and water quality monitoring is managed by the District (mostly outside of the Everglades Division) and other agencies. The Everglades Division has been managing smaller scale hydrologic and water quality monitoring along transects from canal sources through the southern Everglades wetlands (Taylor Slough and the C-111 Basin) and into Florida Bay. Measurements along these transects include nutrient transport and loading to Florida Bay via major creeks in the salinity transition zone (Davis et al., 2003; Sutula et al., 2003; Childers et al., 2006). The District plans to continue these studies, but also need similar characterization and nutrient flux studies through ponds and creeks in the transition zone west of Taylor Slough, where Restoration changes are likely to be most pronounced and where nutrient concentrations tend to be higher than along the northeastern Florida Bay coast. Studies of nutrient loading of Whitewater Bay [(downstream of Shark Slough and expected to receive much more fresh water with implementation of the Decompartmentalization Project (DECOMP)] have been initiated as part of the Florida Coastal Everglades LTER (with Everglades Division participation), but nutrient retention or transport through this bay have not been measured to date. While logistically challenging, documenting and understanding of ecosystem structure and processes within Whitewater Bay is needed for CERP assessment and we intend to initiate this assessment within five years.

Fine-scale spatial patterns of water quality within the Bay, ponds, and creeks (especially in association with fresh water sources) are mapped using the boat-board Dataflow system (Madden and Day, 1992) and will be mapped in Whitewater Bay. Dataflow measures seven parameters (including fluorescence of chlorophyll-*a* fluorescence and dissolved organic matter) every five seconds. New instruments, including a multiple fluorometer and nutrient probes, will be tested and added to Dataflow as technologies become available. Additional spatial mapping of ground water sources within Florida Bay is also being investigated to identify possible sites where ground water nutrient sources may influence algal productivity and blooms. Belowground resistivity and bay water radon (Swarzenski et al., 2006) will be mapped in a subset of bay regions and Whitewater Bay. The District is currently working with UGSS to map the eastern boundary basins of Florida Bay; the approach appears promising for identifying areas where groundwater nutrient fluxes are likely to be highest.

A series of experiments on the bioavailability (decomposition rate) of dissolved organic matter have been run (see *2008 SFER – Volume I*, Chapter 12) and an upcoming workshop on the state of District knowledge on this subject will guide future research. New experiments on the effects of salinity on benthic nutrient fluxes, in particular testing effects on phosphorus fluxes from different sediments and soils, are a high priority. This includes experiments on the drying and inundation of saline wetlands.

Integration and application of information from this project requires several levels of numerical analysis, including calculations of nutrient budgets (improvements of the budget in Rudnick et al., 1999), statistical analysis of monitoring and Dataflow data, mass balance modeling, and dynamic water quality modeling. These approaches are described in the *Synthesis* and *Integration* section of this appendix.

Application of Results: Water quality protection is a core mission of the SFWMD. Water quality assessments, then, are a fundamental part of all modifications of operations and water management structures. While such assessments typically focus on regulatory concerns, ecosystem management and restoration require analysis of nutrient processing, transport, and downstream effects throughout the ecosystem. For Florida Bay, nutrient loading is of particular concern because of its recent history of extensive and prolonged phytoplankton blooms. Thus, the proposed downstream studies are an integral part of the Combined Structural and Operational Plan (for operation of the C-111 Project and Modified Water Deliveries to ENP Project), the C-111 Spreader Project, the Florida Bay and Florida Keys Feasibility Study (FBFKFS, which is evaluating the adequacy of CERP for Florida Bay restoration), and RECOVER.

In particular, a water quality model that is under development as part of the FBFKFS is highly dependent upon results from the proposed project.

Public concerns regarding water management effects on Florida Bay water quality are widespread and either need to be quantitatively refuted or addressed via project modifications to improve water quality (or prevent degradation). The District is legally obligated to protect water quality all parts of the EPA, including Florida Bay. The success of CERP depends, in large part, on success within this most visible portion of the Greater Everglades ecosystem and the path to such success can be illuminated by information proposed in this project.

Seagrass and Ecosystem Studies

Project Overview and Background: The seagrass community of Florida Bay is recognized as the central, keystone, component of the Florida Bay ecosystem (Fourqurean and Robblee, 1999) and is the central performance measure for assessment of the Bay restoration under CERP and other water management programs [see RECOVER Monitoring and Assessment Plan and associated Florida Bay ecological conceptual model (Rudnick et al., 2005)], including Minimum Flows and Levels. The strategic activities of Florida Bay scientists in the Everglades Division are consequently focused on understanding the role of the seagrass community in the Florida Bay ecosystem and understanding the effects of water management on this community, especially with regard to restoration. Understanding the interactions of fresh water flow, salinity change, water quality, and seagrass dynamics is at the heart of the Bay conceptual model. Our approach integrates modeling, fieldwork and laboratory research extending some of our current initiatives. A conceptual/simulation model framework is being used extensively as a synthesizing template for this work. However, the components of our program also stand alone as important probes into seagrass autecology and community dynamics.

Management and Restoration Objectives: The District's research activities will focus on key drivers of the Florida Bay ecosystem and how they influence ecosystem function: salinity, net nutrient and organic imports, seagrass dynamics, and phytoplankton, all to get a better understanding of the "tipping point" (Zieman et al., 1999) relative to ecosystem stability and water management. Ecosystem issues are directly related to validating the effectiveness of MFL rules, outcomes of CERP and Acceler8 projects upstream of Florida Bay, operational planning and assessment (especially CSOP), as well as provide input into the design of restoration strategies under the FBFKFS.

Methods: In addition to managing existing seagrass monitoring contracts for RECOVER, the District will assess the relationships among fresh water flow, salinity, water quality, and seagrass distribution and structure via extensive fine-scale mapping and geostatistical analyses. A primary tool for such comprehensive spatial sampling and analysis is Dataflow (Madden and Day, 1992), which will be run bi-monthly to monitor both stressor (salinity, nutrients, temperature, light regime) and response variables (chlorophyll *a*, turbidity, pH, dissolved organic matter, dissolved oxygen). The District will especially focus on mapping gradients associated with water flowing into the Bay from the mangrove transition zone. Maps of the above parameters will be produced regularly and be used to monitor Bay conditions, provide spatial data for statistical and dynamic modeling analyses focused on phytoplankton blooms, HABs, seagrass loss and nutrient processing. Concurrently, the District will also explore methodologies for seagrass bed continuous mapping using hydroacoustic or side-scan sonar (approaches currently being tested in the District's Coastal Ecosystem Division). Geostatistical analysis of fine-scale spatial data on water quality and SAV should illuminate relationships between water column and benthic conditions and lead toward hypothesis refinement and improved modeling.

Research of seagrass community responses to changing fresh water flow, in association with the development of the seagrass model, will proceed. The District will contract for mesocosm research that measures nutrient uptake and kinetic parameters of seagrasses under different inter-specific competitive scenarios, and conduct ground-truthing field verification studies of these findings. Implications of sulfide, light, and salinity stressors on inter-specific competition and productivity patterns will be investigated within the controlled mesocosm environment.

Research of phytoplankton dynamics and light extinction in Florida Bay will also proceed (see the *Florida Bay Algal Bloom* section of this appendix) via landscape scale analysis of data from the SFWMD/FIU water quality monitoring network (Boyer and Keller, 2007), and collaborations that will be initiated to research processes influencing planktonic and benthic productivity patterns (particularly experiments on the role of dissolved organic matter; Glibert et al., 2004). The role of microphytobenthos has been found to be particularly important with regard to productivity and nutrient cycling patterns (Nagle, 2004) and the District anticipates the need for experiments on algal mats to parameterize the seagrass model, although given current staffing and funding levels, such an initiative may be delayed toward the end of the current five-year planning period.

Application of Results: Many of the applications of the proposed research will occur through the modeling process. A phytoplankton simulation model module will be developed and integrated into the seagrass community ecological model (Madden and McDonald, 2006) that will allow increased predictive capability of system responses to hydrologic changes. Nutrient mass balance and phytoplankton competition with seagrasses for nutrients will be evaluated using information gained from mesocosm experiments and modeling analysis. Output from the emerging mangrove transition model effort will provide links to the nutrient speciation in input waters. Algorithms for water column light attenuation based on phytoplankton species and concentration will be established. Linkage of the phytoplankton-seagrass model will be made to the EFDC hydrodynamic transport framework, and a 3-D landscape-level water quality model. The developing model code will be fully compatible with the emerging 3-D hydrodynamic water quality model at a landscape scale being developed for Florida Bay (Hamrick 2006).

These information syntheses will build our understanding and predictive capability so that the District will improve our ability to determine the effects of ongoing water management for the 2011 MFL update, operational planning (e.g., CSOP), restoration planning within CERP's Florida Bay and Florida Keys Feasibility Study and the C-111 Spreader Canal Project.

Submerged Aquatic Vegetation (SAV) Modeling

Project Overview and Background: Since 2000, an evolving simulation model of the SAV community ecosystem in Florida Bay has provided an integrative approach to establishing performance targets and predicting ecosystem responses to water management strategies. The model, developed and maintained in-house at the Everglades Division of SFWMD, is a mechanistic, process-based simulation framework for predicting the biomass, distribution and species composition of the dominant seagrasses in northern and central Florida Bay. It examines *T. testudinum* and *H. wrightii* response to multiple environmental variables, including salinity, and provides estimates of biomass under a variety of freshwater inflow conditions. The conceptual design of model component interactions is depicted in **Figure 4**. Plans for 2007 through 2009 are to continue model development and refinement as an autonomous system as well as to integrate it into the EFDC hydrodynamic/water quality model currently being developed for Florida Bay (Hamrick, 2006). This initial version of this model has already been applied for the development of Florida Bay Minimum Flows and Levels (MFLs), which were established in 2006 based largely on estimates of the effects of salinity on SAV habitat as a valued ecosystem component. The SAV model is an integral part of CERP's Florida Bay and Florida Keys Feasibility Study (FBFKFS), with associated peer review by Stevenson et al. (2006) and the Interagency Modeling Center.

Management and Restoration Objectives: The specific goals and applications of the SAV model are to develop an understanding of how the seagrass community responds to environmental forcings, test hypotheses, and predict system response to restoration actions. Model runs are targeted to optimize water management strategies that enhance the health, desirable biomass levels and species mix of the seagrass community for different regions of Florida Bay. The model will be used to identify and refine target salinity ranges to meet these target objectives while identifying actions that could trigger adverse consequences in the water column such as phytoplankton blooms.

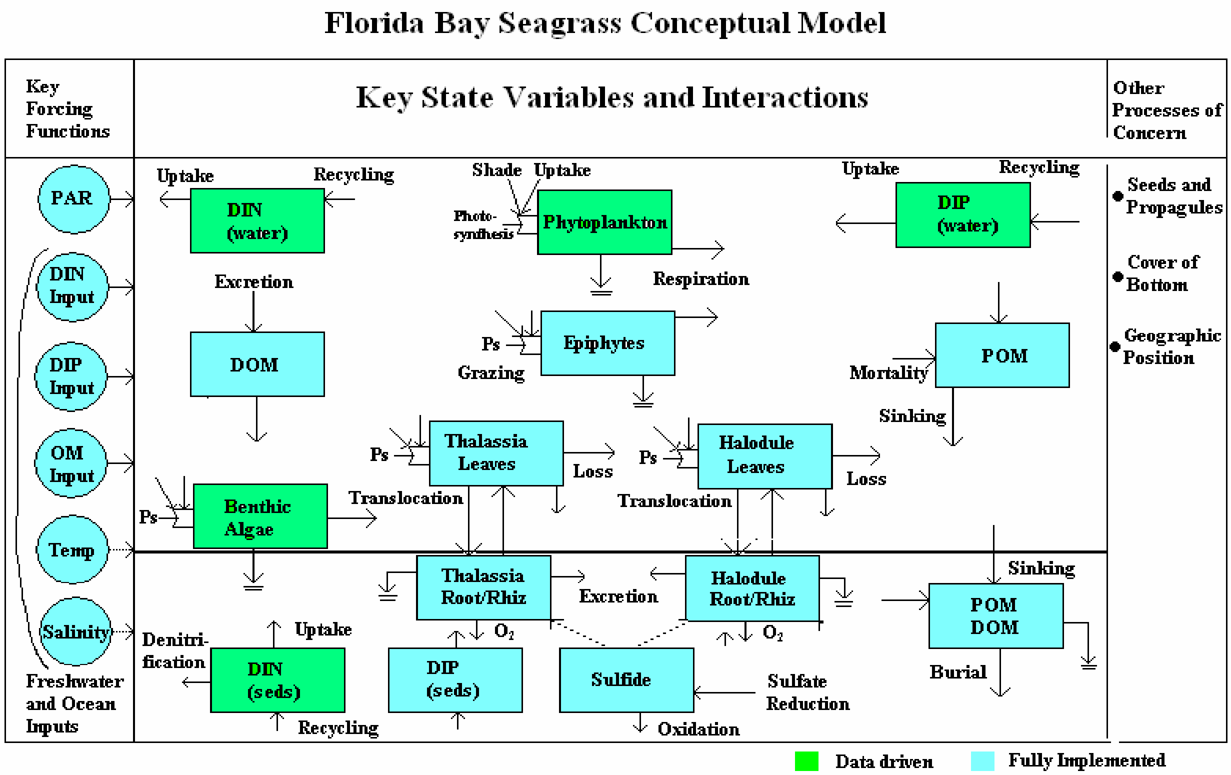

Figure 4. Conceptual model showing major components and interactions of the Florida Bay SAV community model.

Methodological Approach: The model is a stand-alone system of linked ordinary differential equations running on both MATLAB and FORTRAN platforms. Currently the stand-alone seagrass model runs using inputs of salinity from the FATHOM transport model (Cosby et al., 1999), seagrass cover and biomass estimates from the M-D DERM and FHAP programs and nutrients from several long-term monitoring programs, most notably selected Florida Bay stations of the SFWMD/FIU water quality monitoring network (Boyer and Keller, 2007).

Strategic modeling activities of the Florida Bay modeling team are directed toward extending the existing SAV model (Madden and McDonald, 2006) to incorporate field and lab data from several projects. In line with the District's Strategic Plan for 2007–2017, the District will be concerned with refining and updating model structure and model parameters using information from experimental and monitoring efforts. Model experiments will indicate experimental approaches or treatment levels that will be implemented in subsequent field measurements. *Ruppia maritima*, a major species of the Salinity Transition Zone ponds and which may expand into Florida Bay proper with Restoration, will be added to the model within one year. The phytoplankton module will be fully inserted into the ecological model within two years. Nutrient mass balance and phytoplankton competition with seagrasses for nutrients will be enabled. Algorithms for water column light attenuation based on phytoplankton species and concentration will be established. Model code will be fully compatible with the emerging 3-D hydrodynamic water quality model at a landscape scale to be developed for Florida Bay (Hamrick, 2006).

Linkage of the phytoplankton-seagrass model will be made to the EFDC hydrodynamic transport framework, and a 3-D landscape-level water quality model.

Application of Results: The model is calibrated for a 1996 through 2001 baseline period and achieves a stable steady state after about three years. All scenario and calibration runs are evaluated following a 10-year initialization period to eliminate transients and initialization artifacts. The model has most recently been used to implement MFLs for Florida Bay in developing statutory minimum water delivery requirements to prevent significant harm to the Bay. The MFL Rule adopted by the District and FDEP requires a reassessment within five years. The District will apply the new three-species model for this reassessment.

Output from the modeling project proposed here will link directly to simulation models being developed for use by CERP and other management programs in predicting seagrass and ecosystem responses to water management. Restoration alternatives will be tested using the model to project short (2010) intermediate (2025) and long-term (2050) outcomes of restoration activities under the FBFKFS, the C-111 Spreader Projects and will also be used for MFLs and operational (CSOP) evaluations. The Florida Bay SAV and ecosystem process model will enable the District to evaluate both direct and indirect downstream effects of management activities on the Florida Bay ecosystem.

ANALYZING LANDSCAPE STRUCTURE AND FUNCTION

The Greater Everglades Landscape is a patterned peatland that developed under pre-drainage unrestricted flow conditions. Its original extent was over most of the landscape south of Lake Okeechobee. This landscape is characterized by elevated sawgrass ridges regularly interspersed among lower and more open sloughs that are elongated and aligned parallel to the historic flow direction. Historically, the formation and maintenance of the landscape is the long-term interaction and feedback product of physical (hydrology, nutrients, fire, etc.) and biotic processes (vegetation production, turnover, decomposition, etc.) of the Everglades wetland. In the past century, anthropogenic modification of this landscape, such as digging canals, building levees, and increased nutrient enrichment, has significantly modified water levels, hydroperiod, and flow direction, which largely resulted in the degradation of the unique ridge-and-slough landscape by altering vegetation patterns and flattening microtopography. CERP is obligated to investigate the past, current, and future of the ridge-and-slough landscape for its formation and maintenance mechanisms to establish appropriate goals for restoration and criteria of restoration success.

The need to study and understand large-scale structure and function will be critical to the evaluation of CERP restoration plans for the next 10 years, the assessment of implemented restoration projects for the next 20 years, and to the regulation schedule adjustments needed for sound resource management for the next 100 years. The District manages the water supply network in a holistic, integrative manner, which means that the surrounding extant Everglades must also be ecologically understood in a holistic, integrative manner. However, this is a difficult task because, (1) large-scale features tend to be well-buffered and relatively slow to change, (2) landscape-scale functions have large spatial variability, (3) it is difficult to quantify temporal trends into influences from separate allochthonous and anthropogenic stressors and drivers, (4) large-scale analyses are difficult to implement and costly to maintain, and (5) economic and political vagaries make landscape research programs difficult to maintain.

To compensate for these difficulties, the strategy for the analysis of landscape structure and function must be logistically feasible and well-focused. Programs outlined below are expected to quickly reduce uncertainties and provide enough critical, much-needed information, to allow restoration plans to be designed and implemented. These large-scale programs are designed to complement the wildlife and ecosystem programs presented earlier. The Everglades Division will then be able to provide the guidance and basis for CERP adaptive management strategies. In particular, these landscape programs will "feed" the Incremental Adaptive Restoration (IAR) program, as recommended by the National Research Council (2006).

Primary RECOVER Hypotheses that will be in addressed in part by the projects described in this section are:

Hypothesis 8: Everglades Ridge-and-Slough Microtopography and Landscape Pattern in Relation to Organic Soil Accretion and Loss (see the *Ecosystem* section of this appendix)**.**

Hypothesis 9: Sea Level and Freshwater Flow as Determinants of Coastal Transgression (see the *Ecosystem* section of this appendix)**.**

Hypothesis 10: Sea Level and Freshwater Flow as Determinants of Production, Organic Soil Accretion, and Resilience of Coastal Mangrove Forests (see the *Ecosystem* section of this appendix)**.**

Hypothesis 13: Rainfall and Sheetflow as Determinants of Natural System Hydrologic Characteristics in the Everglades.

The volume, timing, and distribution of sheet flow, in combination with direct rainfall, produced fundamental hydrologic and landscape characteristics of the pre-drainage Everglades:

- Hydroperiod and water depth patterns
- Rainfall-driven pulsed flow events
- Hydraulic residence time
- Landscape form and pattern
- Surface water contact with substrates and biota
- Surface water/groundwater interactions
- Freshwater flows supporting beneficial salinity patterns in the mangrove estuaries of Florida Bay and the Gulf of Mexico

Compartmentalization has altered or eliminated sheet flow and related natural system hydrologic and landscape characteristics throughout the Everglades. Decompartmentalization combined with resumption of natural volume, distribution, and timing of freshwater delivery is expected to restore sheet flow and pre-drainage hydrologic and landscape characteristics to an undivided ecosystem encompassing much of WCA-3A, WCA-3B, eastern Big Cypress, and the ENP.

RIDGE-AND-SLOUGH STRUCTURE AND FUNCTION

The District's research strategy for this aspect of the program will need to define clear interim objectives and milestones. Programs outlined in the tree island and ridge-and-slough assessments are expected to quickly reduce uncertainties enough to allow restoration plans to develop and water management to improve. However, even though these results may suggest significant modifications to the current resource management policy and structure, the environmental and legal risks associated with large*scale alterations may be deemed too great. The Everglades Division will then provide the guidance to develop and implement more adaptive management strategies, such as the Decomp Physical Model. An Incremental Adaptive Restoration (IAR) program, as recommended by the National Research Council (2006), will create a framework for landscape assessments and hypotheses testing at scales that can have significant restoration impacts and scientific results at the same time.

Vegetation Mapping

Project Overview and Background: The distribution, types and quality of vegetation are still largely unknown in many parts of the remnant Everglade's environment. This lack of information hinders the management of these resources. An essential component of effective management is to know where distinct or degraded habitats occur so that they can receive a higher level of proactive or restoration protective measures. This strategic plan stresses the need to conduct coordinated, comprehensive vegetation mapping of Everglade's habitats to improve their management. The technologies used to acquire these types of data are changing rapidly and therefore, the most cost efficient methods to obtain maps are also subject to change as the technology evolves. This strategic vegetation mapping plan will remain a dynamic document that will be revised as protocols and technological capabilities progress. Landscape maps are a vital tool that allows managers to visualize the distribution, diversity, and extent of vegetation communities under their jurisdiction, and they will contribute considerably to the comprehensive planning and management of those resources.

Management and Restoration Objectives: The goal of this part of the Division's research plan is to conduct coordinated, comprehensive vegetation mapping of the greater Everglades. The audience for the map products will encompass a more diverse stakeholder community, including local residents, resource managers, consultants, scientists, tribal interests and environmental organizations. These data provide an integral and integrative metric for other research activities that investigate the importance of various habitat types for the survival and growth of other organisms across spatial and temporal scales.

Methodological Approach: There are four steps required to make vegetation maps: data acquisition, ground-truthing and processing, interpretation and quality assurance and quality control of data, and distribution of the results. There is a large variety of equipment used to obtain data needed for vegetation mapping. The types of equipment most suited for a particular area depend on the types of data to be gathered. Vegetation data is usually obtained via remote sampling methods such as through video, aerial photographs, Light Detection and Ranging (LiDAR) or aerial/space-borne multi-spectral imagery. These approaches vary in their data acquisition methods, in their resolution, and in their relative strengths and weaknesses. Current vegetation mapping is being conducted every six years with the acquisition of 1:24,000 scale color-infrared aerial photography, which is then processed using conventional photogrammetry. New LiDAR sensor technology combined with high-resolution digital imagery will also be tested for quantifying total biomass volume of vegetation over specific tree islands distributed across each of the WCAs. LiDAR is a remote sensing technology used to measure vertical profiles of natural and man made objects. Primarily used in topographic mapping applications LiDAR has also been used successfully to map wetland and forest vegetation vertical profiles and structural properties.

Application of Results: The vegetation mapping plan is designed to explore technical aspects associated with vegetation mapping in the Everglades, specifically for parameterizing landscape spatial variation. Among the many potential benefits of this data will be options to investigate large scale habitat relationships and long-term temporal dynamics. With these maps the changes through time can be assessed at the landscape scale relative to restoration efforts and operational changes. Utilization of mapping technologies leverages the full utility of data (e.g., soil, water quality, algae) already collected for other purposes.

Historic Dynamics of the Landscape Mosaic: Paleoecological Studies

Project Overview and Background: Over the last century, water management has drained and compartmentalized the Everglades, degrading the ridge-and-slough landscape, tree island communities, and flattening the pre-existing microtopography (Sklar et al., 2002; SCT, 2003). The impacts of successive drainage and impoundments have produced varying changes throughout the remaining Everglades. To establish targets for restoration, it is important to understand pre-drainage conditions of the Everglades.

Three types of information provide insights into these conditions. The earliest quantitative information about the original landscape is available through the use of paleoecological records derived from peat cores that indicate plant species and vegetation communities extending back hundreds to thousands of years (Willard et al., 2006; Saunders et al., 2006, 2007; Bernardt et al., 2004). A second, intermediate type is available as early historic accounts of the landscape as explorers, settlers, military expeditions, surveyors, and other visitors documented what they saw (McVoy et al., in review). These records are being addressed thoroughly by McVoy et al. (in review). A third type is available through aerial photography that began in 1940 and followed generally each decade thereafter that provide images of the changing landscape (Nungesser, submitted). The success of restoration projects aimed at restoring the vegetation and hydrology of the Everglades landscape requires, above all, a clear understanding of pre-drainage conditions (Davis et al., 1994; SCT, 2003).

These projects provide both short- and long-term records of the ridge-and-slough landscape, with its regularly spaced ridges, sloughs, and tree islands, as it responded to long-term natural hydrologic conditions, local and regional alteration to hydrologic flow and to larger-scale environmental conditions produced by peatland drainage, fires, and impoundment. Altered hydrology has impacted landscape patterns in ways that can be traced through paleoecological records, through historic records, and through changes in surface morphology that will help to determine the pre-drainage conditions and the effects of canals, levees and levee modifications on landscape patterns and tree islands.

Management and Restoration Objectives: This research addresses several restoration objectives of Hypothesis 8 and Hypothesis 13, including (1) quantifying pre-drainage hydrology, vegetation and soil development; (2) quantifying the extent to which past hydrologic changes (natural and managed) have coincided with changes in plant species abundance, ecotone boundaries (e.g., ridge-slough, tree island tail-marsh), and soil accretion over multi-decadal and century time scales; and (3) corroborating and validating aerial imagery, specific to areas characterized as wetting, drying, and “relatively stable” from 1940 to present.

Methodological Approach—Paleoecological Analyses: Paleoecological data from Everglades soils can provide information about past vegetation, soil accumulation, fire frequency, and hydrologic conditions over time periods ranging from decades to centuries (Winkler et al., 2001; Saunders et al., 2006; Willard et al., 2006). Changes in Everglades habitats have been linked to millennial scale changes in the Florida climate (Winkler et al., 2001; Willard et al., 2006), but more investigations are needed to resolve the effects of 20th century water management activities (Willard et al., 2006). Paleoecological analyses of Everglades soils have been used to demonstrate changes in ridge-and-slough boundaries at the resolution of 30 meters (Bernhardt et al., 2004) or less (Saunders et al., 2006 and 2007), thereby enabling researchers to use both paleoecological and aerial imagery approaches to quantify and understand changes in ridge/slough boundaries. The research described here will integrate paleoecology with analyses of historic records and aerial imagery to provide fine-scale data on vegetation, soil, and hydrologic changes from pre-drainage to modern periods (**Figure 5**).

Specific paleoecological investigations will focus on four key subregions, including: (1) a historically drained area; (2) an impounded area; (3) a "stable" area (ridge-and-slough patterning relatively unchanged); and (4) an area to be hydrologically affected by the DECOMP Physical Model experiment. Subregions will be selected based on aerial imagery analyses (per M. Nungesser, personal communication) of 15 landscape quadrants (4 km x 6 km) in WCA-3 (see *Ridge and Slough Pattern Analysis and Modeling*, **Figure 8**). At each of the four subregions, 6 to 8 cores will be collected along a 100-meter ridge-and-slough transect (total of four transects, 24–32 cores total) that is located in the approximate center of the 4 km x 6 km landscape quadrant. Cores will be analyzed for ^{210}Pb and ^{14}C to establish soil dates for each core. Paleoecological proxies, including macrofossils (mainly seeds), pollen and biomarkers, will be used to quantify changes in ridge/slough boundaries, including pre-drainage and early drainage conditions (before 1940) and after 1940, when water management began in earnest.

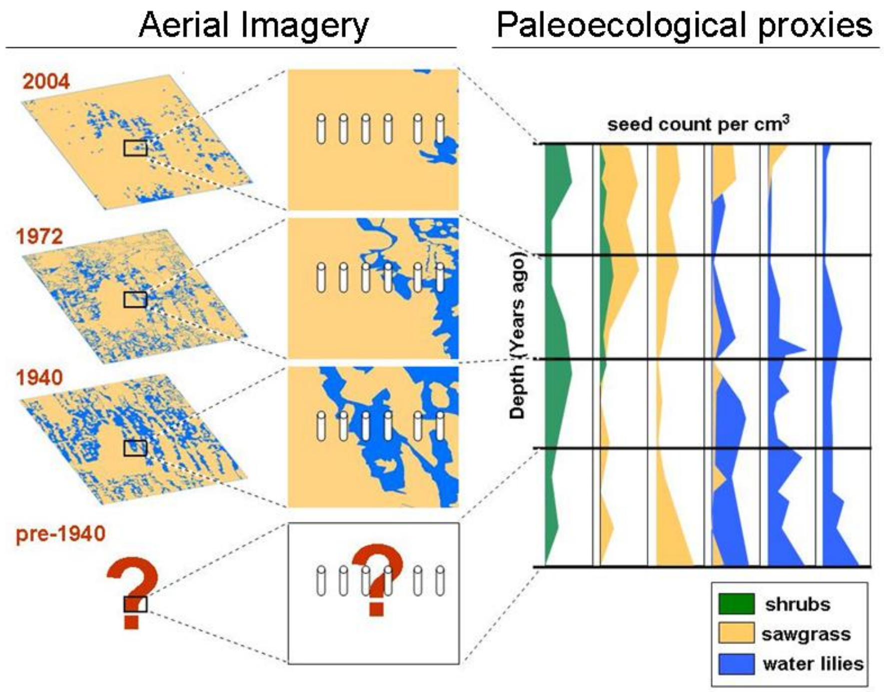

Figure 5. Research plan overview: integrating paleoecological reconstruction with image analyses. Soil profiles of paleoecological proxies (exemplified here as fossil seeds) from cores collected along ridge-and-slough transitions will validate aerial images from 1940 through 2004 and quantify pre-1940 vegetation, peat accretion and hydrology.

Application of Results: Ridge-and-slough microtopography and tree islands are central to the Everglades' identity as a wetland, and are essential to wildlife use and conservation. Understanding how these features formed and the hydrologic conditions that maintained them is essential to optimizing water management for restoration. This investigation reduces the uncertainty about hydrologic and biological (vegetation) conditions that lead to restoration (or loss) of historic ridge-and-slough landscape conditions and tree island communities. It also reduces the uncertainty about the rate and intensity of ecological responses to be expected in adaptive management activities such as the DECOMP Physical Model experiment. Finally, this research provides a unique data set for validating aerial imagery and for synthesis and modeling research used to quantify and understand restoration measures on future ecosystem stability.

Figure 6. An oblique aerial view of the four, 15-acre macrocosm cells, with two 0.75-acre tree islands in each, soon after construction in 2001. Photo by SFWMD.

Flow Effects on Plant Community Interactions

Project Overview and Background: The Loxahatchee Impoundment Landscape Assessment (LILA) facility is an 80-acre physical model designed to replicate the Everglades landscape in order to provide a platform for multi-disciplinary research **(Figure 6)**. This project will utilize the LILA site to analyze how flow rate and water depth interact with ridge-and-slough habitat structure. The central portion of the historic Everglades was a flow-way characterized by a corrugated ridge-and-slough landscape. The loss of the ridge/slough dynamic has been largely attributed to the loss of spatial patterning resulting from reduced flow. However, experimental evidence that separates the effects of flow from those of water depth and hydroperiod is lacking, as is how the interaction between flow and nutrients affects these processes. The objective of this project is to quantify a flow regime necessary to build or rehabilitate the Everglades ridge-and-slough habitat.

Management and Restoration Objectives: Get a better understanding of the ecological basis for slough community change in the absence of nutrient loading so as to preserve their hydrodynamic functions.

Methodological Approach: In order compare the effects of water depth and flow rate and to examine sedimentation, soil-building and nutrient dynamics, strips of vegetation composed of blocks of three keystone Everglades wetland species have been planted in 2 m x 2 m patches (**Figure 14**). These strips were planted at two depths and two flow rates in the sloughs of each cell, as well as on the interior and edge of a ridge in each cell. In each cell, an upstream portion of one ridge is built out in to the adjacent shallow slough to constrict flow and thus increase water velocity in this area of the shallow slough, while the constructed tree islands constrict flow in the deep slough. This built-in variation in flow will be utilized to provide a within-cell flow velocity treatment. Additionally, two of the cells will have slow flow, while two will have higher flow, giving a between-cell difference in flow rate.

As depicted in Figure 6-14 of Chapter 6 of this volume, the three species planted are sawgrass (*Cladium jamaicense*), spikerush (*Eleocharis cellulosa*), and water lily (*Nymphaea odorata*). These three species have very different growth forms that could, in turn, affect local flow rates and sedimentation differently. Intermixing plantings of sawgrass, spikerush, and water lily under different flow rates and water depths, then monitoring sedimentation and soil accretion, as well as growth of each species, will help the District understand how these species affect the landscape (i.e., function as "ecosystem engineers") and to determine whether morphology of the different species results in local differences in flow rate and soil-building processes. The hypothesis is that species morphology alone can create ridge, slough, and wet prairie topographies through effects on sedimentation, given sufficient flow, but that the water depth-flow rate interaction determines a species' ability to grow. Additionally, comparison of direction of expansion of the plantings on the edge of the ridges to plants in the interior, as well as rates and direction of expansion around blocks of plants in the sloughs, allows us to examine species expansion versus contraction under different flow rates within a cell.

This planting configuration will allow monitoring of growth and sedimentation in a hydrologic environment that is already channelized and where each species grows in an isolated patch. Each species was just recently planted at initial densities of one plant per 0.25 m^2. Growth will be monitored by counting the number of stems in six permanent 0.25 m^2 quadrats in each block, one on each of the four edges and two in the interior. Leaf length and number of leaves per plant will be determined for each of these quadrats. There will be no leaves in these edge quadrats initially, but these are expected to fill in over time. This design allows us to determine whether the growth into these areas is related to direction of flow, water depth, and/or flow rate. Sediment traps will be set out upstream, downstream, and inside of vegetation blocks to document rates of sedimentation. Local velocity measurements around each block will be collected in conjunction with sediment trap collections. The data will be analyzed for the effects of flow rate, water depth, and their interaction on growth and productivity of each species and results will be compared among species.

Application of Results: There is a large gap in our ability to quantify restoration targets for flow rates in the Everglades. Without this knowledge, the ridge-and-slough pattern may continue to disappear despite interagency efforts to increase hydroperiods and depths. The information gained from the experiment will contribute to the District's ability to: (1) predict whether increased flow will lead to Everglades restoration, (2) provide a target flow rate for Everglades restoration, and (3) help resource and restoration managers better understand how water flow and depth interact with ridge-and-slough plant structure.

Meta-Scale Transport Processes: Natural and Manipulated

Project Overview and Background: The ridge-and-slough landscape of the Everglades includes several sensitive aspects, including large-scale (minimum unit cell for patterning of approximately 400 hectacres); chemical sensitivity (especially calcium and phosphorus) of the primary transportant, flocculant organic material; a highly unusual flow regime, with uniform velocity field over tens of kilometers; very low slopes (about 10 to 5); and strong vegetation community sensitivity to known and unknown water chemistry. These characteristics suggest that development of a mechanistic understanding of the processes sustaining the original patterning requires a multi-pronged, multi-scale approach. Some questions are well-suited to time series remote sensing studies, others to laboratory measurements, and still others to mesocosms. However, in all likelihood, some questions can only be answered through field measurements located within large areas of the actual landscape. Large (in this case) would be defined by the landscape characteristics, that is, areas corresponding to multiple unit cells all experiencing uniform flow fields. The studies described in this section of the appendix are intended to complement the other sections of this plan by providing data and, hence, foster understanding of landscape processes under manipulated field conditions and actual, corresponding field conditions as they were to pre-drainage ridge-and-slough conditions.

To date, the ecological significance of flow in the Everglades remains poorly understood despite the 2003 Science Coordination Team report identifying it as a critical research need for the successful implementation of CERP. This is especially true for the CERP Decompartmentalization project (DECOMP). There is considerable scientific and engineering uncertainty over how the ridge-and-slough landscape will respond to changes in water delivery and how to achieve sheetflow. The DECOMP Physical Model (DPM) is a multi-agency, multidisciplinary project created to address these uncertainties. DPM takes advantage of the construction of water control structures on the L-67A levee and modifies the location and size of gaps in the L-67C levee that are being built as part of the Modified Water Deliveries Combined Operational Structural Plan, to specifically address the physics of sediment transport and the ecological function of sheetflow (**Figure 7**).

Management and Restoration Objectives: It appears that the ridge-and-slough landscape developed and persisted under a hydrologic regime of uniform sheetflow. Now, management needs to determine whether long-term sustainability of the remaining ridge-and-slough landscape also depends on a uniform flow field. The management goal is to develop sufficient process understanding to determine the system alterations needed to ensure long term sustainability of the ridge-and-slough landscape. More specifically, this research addresses several restoration objectives, including (1) quantifying the ecological benefits of sheetflow; (2) evaluating the physics of sediment transport and the role of canals in this process; (3) examining the resilience of tree islands to increased flooding; and (4) providing hydrodynamic data for the District's water management models.

Methodological Approach: These five elements examined across a broad region of manipulated, impacted, and "natural" habitats will highlight base-line information and supply restoration targets:

- Estimation of pre-drainage slough velocities
- Velocity differences between ridges and sloughs
- Buoyancy studies
- Long-term *in situ* process studies
- Studies of analogous patterned peatlands

Briefly, the DPM will connect WCA-3A and 3B via three weir-culvert structures on the L-67A levee in combination with seven 3,000-foot gaps in the L-67C levee. The weir-culvert structures will be operated to achieve targeted water velocities in the gaps in the L-67C without violating any of the current water level constraints. Sediment transport and ecological studies will be performed in the gaps over a three-year period and compared in a statistically sound design to the control or "no flow" regions. Sediment transport at different flow velocities will be evaluated using *in situ* benthic annular flumes and sediment tracers that are "hydraulically matched" to native sediment particles. This will be coupled with tracer studies of the water mass and colloidal particles, as well as, microbial and vegetation studies to evaluate how flow influences ecological processes such as decomposition and productivity. Similar studies will be conducted at "reference" and "impacted" locations across broad regions of the Everglades.

Application of Results: Absent a knowledge-based tool for predicting the effects of different Everglades restoration scenarios, society runs the risk of spending very large sums of money while choosing a scenario that does not provide long-term protection for the principal remaining portion of the Everglades, the ridge-and-slough landscape. DPM studies associated with flow, sediment movement, DOC transport, belowground processes of decomposition and accretion, and resistance to change, will all provide the critical information required to move the de-fragmentation of the Everglades by providing the DECOMP Project with the quantitative tools needed to evaluate restoration alternatives. The understanding of slough processes gained from these studies will be used to evaluate the likelihood of management and restoration to achieve long-term sustainability of the remaining ridge-and-slough landscape.

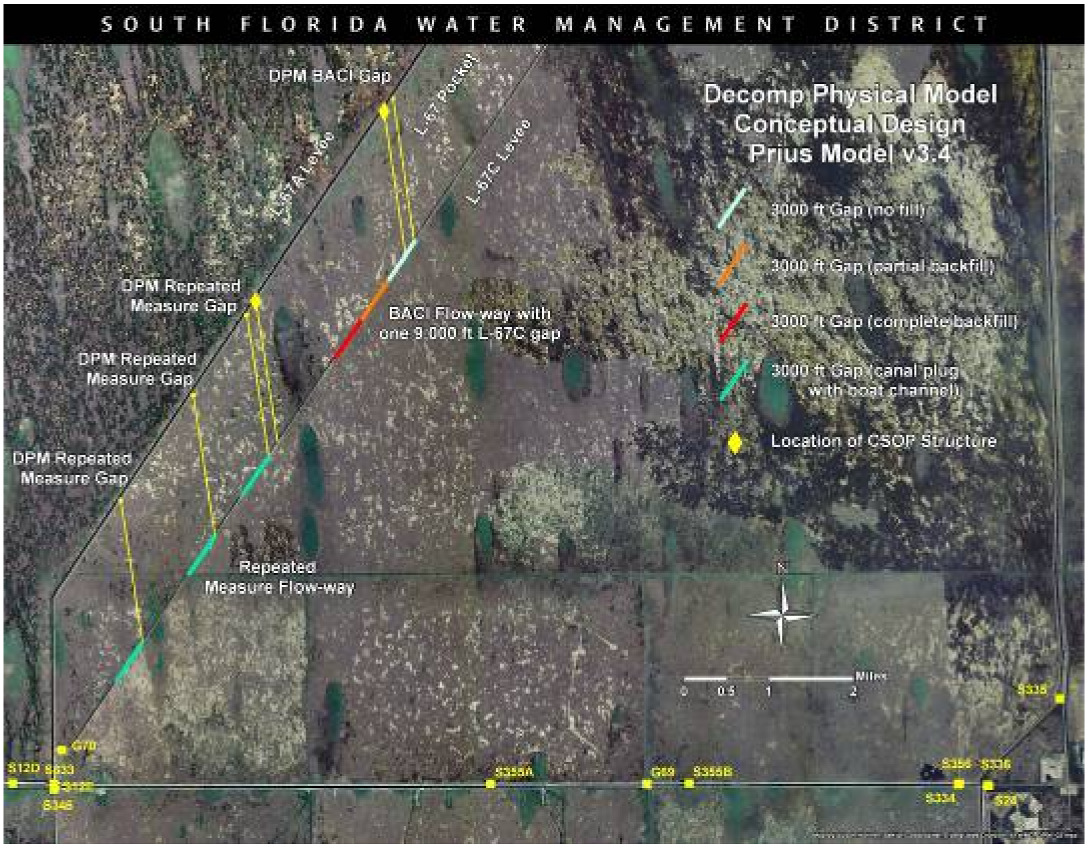

Figure 7. New hydrologic structures on the L-67A canals will move water out of WCA-3A and into WCA-3B as a controlled adaptive management experiment designed to look at the physics and ecology associated with sheetflow in a shallow peatland environment.

Ridge-and-Slough Pattern Analysis and Modeling

Project Overview and Background: The ridge-and-slough landscape of the Everglades is a patterned peatland that developed under pre-drainage, unrestricted flow conditions. Its original extent was over most of the landscape south of Lake Okeechobee. Research continues to document how the original ridge-and-slough landscape patterns have degraded or disappeared as a result of modified hydrology. The processes leading to this regular and distinctive patterning are not yet understood but appear to relate to flow and peat accumulation processes.

Two complementary approaches will provide insight into the processes leading to the landscape patterning. First, aerial imagery beginning in 1940 and continuing generally every decade thereafter provides a means to track surface-pattern changes over time. Degradation and disappearance of these patterns can be tracked over the decades through this imagery, providing keys to how altered hydrology and patterns interrelated. Impoundment and drainage histories vary throughout the remaining Everglades, but some general trajectories have been seen. Drainage caused ridge vegetation to expand into sloughs, woody species to invade, microtopography to degrade, and fire frequency and intensity to increase. Subsequent ponding reversed some of these effects, but did not restore patterning. This project addresses the details of how altered hydrology has impacted landscape patterns. The evidence may suggest to what extent restoration activities can succeed in reversing historic pattern degradation.

The second approach is development of the Ridge-and-Slough Pattern (RASP) model, a simple, rule-based model that will lead to better understanding of mechanisms leading to the ridge-and-slough patterning. The RASP model will provide a means of testing some of the hypotheses that arise from the historic analysis, specifically how this landscape formed and is maintained. This project will (1) suggest what landscape attributes are responsible for pattern generation; (2) investigate changes that occur from flow impediment, depth changes and other hydrologic alterations; (3) relate simulated patterns to actual historic patterns under original and altered hydrologic conditions; and (4) investigate how, and if, degraded landscapes can be restored under improved flow and depth conditions.

Management and Restoration Objectives: Historic pattern changes and its focus on determining the original, pre-drainage landscape will help establish restoration targets. Specifically it will provide the following:

- Determine what the ridge-and-slough landscape looked like in 1940.
- Quantify changes in the ridge-and-slough and tree-island patterning that have occurred in WCA-1 from 1940 through the present as a function of water management and altered hydrology.
- Characterize the effects of water management on these pattern changes.
- Provide data for trajectory analysis to hindcast these patterns to pre-drainage times that will serve as measurable, quantified targets for restoration.
- Serve as a baseline for measuring alterations caused by restored hydrologic flows.

Methodological Approach: Fifteen quadrants, located along three major flow paths from north to south in WCA-3 (**Figure 8**) have been selected to determine changes in patterning, as well as to follow future changes with restoration of flow from restoration. The quadrants are 4 km x 6 km in size to include multiple ridges and sloughs in both length and width. Within each quadrant, all ridges and tree islands (non-slough landscape components) are being digitized, and then temporal changes in percent cover, pattern orientation, mean length, mean width, length-width ratios, perimeter-area ratios, and other spatial metrics are calculated for each quadrant. Quadrants will be compared across time and space to determine the extent and types of pattern changes that have occurred. Paleoecological analyses will supplement and validate visual changes to these landscape elements, and data will feed the RASP model.

The RASP model will investigate the role of flow by structuring simple decision rules designed to relate flow and depth to vegetation in a cellular automata landscape. This simulated landscape is structured as a large matrix of square grid cells with each cell assigned initially at random as either sawgrass or slough vegetation. Elevation is calculated for each grid cell based upon an overall slope for the grid. Water follows the slope downward and is partially diverted by sawgrass cells. This, in turns, alters the depths, which then alters the vegetation that alters the pattern. Stable patterns can emerge that mimic the dominant attributes of the original landscape, such as elongated ridges parallel to flow, regular spacing, slough connectivity, proportions of ridges and sloughs, ridge size and dimensions, and even diversity of ridge shapes.

Application of Results: Ridge-and-slough microtopography and tree islands are central to the Everglades' identity as a wetland, and are essential to wildlife use and conservation.

Understanding how these features formed and the hydrologic conditions that maintained them is essential to optimizing water management for restoration. Spatial pattern changes across a broad range of flow-impacted regions can be related to water management practices, hydrologic structures, and climatic events to suggest relationships between hydrology and pattern changes. These changes will be compared to those produced by the DECOMP Physical Model.

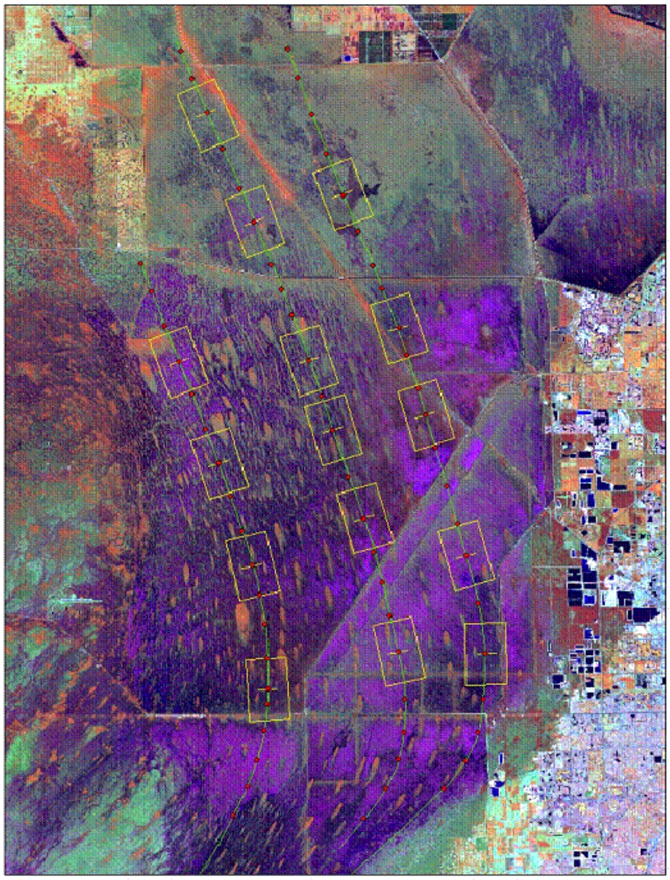

Figure 8. Quadrant locations for project on ridge-and-slough historic pattern changes in the Everglades. Each quadrant is 4 km x 6 km in size, oriented parallel to the dominant directionality of the patterns.

Process-based understanding of the formation and maintenance of the ridge-and-slough landscape is poor. RASP suggests some of the basic processes involved in the patterning, directing research towards more promising lines for future investigations. The simplicity of this model allows rapid testing of hypotheses. Results from pattern change analyses and RASP will suggest the flow velocities, timing, depths, and seasonalities that are necessary to maintain existing patterns and to improve or restore the degraded patterns of the landscape.

TREE ISLAND STRUCTURE AND FUNCTION

As an integral part of the Everglades landscape, tree islands developed under a poorly understood combination of natural wetland processes, geophysical characteristics, and climate variability (Willard et al, 2006). Furthermore, the hydrology of the Everglades has been dramatically altered during the last century, and it is suspected that tree island loss is the result of the water management practices that influence the hydroperiods of tree islands (Sklar and van der Valk, 2002). For instance, the number of tree islands between the 1940 and 2005 decreased about 80 percent in WCA-2 and 60 percent in WCA-3 (Sklar and van der Valk, 2002). Over the last 60 years there has been a decline in density, species composition, and tree-island size that has prompted efforts to answer fundamental ecological questions about the environmental factors that control the tree island/ridge-and-slough landscape development specific to the Everglades.

Tree islands are a significant spatial feature of the Everglades wetland because they are biodiversity hotspots in an oligotrophic landscape. Although these islands comprise less than 10 percent of the extant Everglades, they provide scarce refugia, nesting, and foraging habitat for a wide variety of terrestrial and wetland mammals, birds and reptiles (Sklar and van der Valk, 2002). However, in the central Everglades where restoration is expected to improve and preserve tree islands, little is known of tree-island composition, canopy structure, plant health, and soil accretion and formation in relation to island geophysical characteristics.

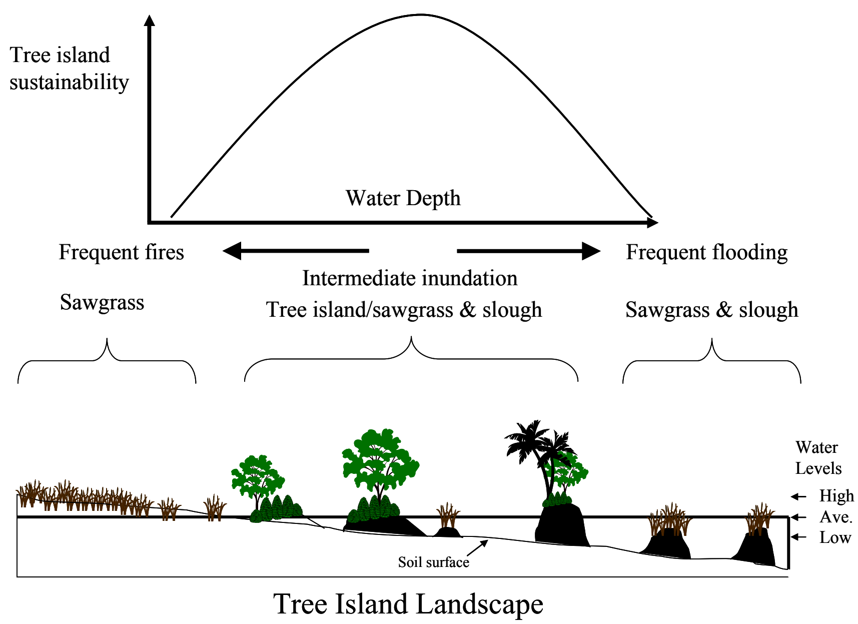

Figure 9. Conceptualization of the spatial and temporal distribution of tree islands in the Everglades in relation to the subsidy-stress hypothesis of Odum and Odum (1981).

Tree islands' elevations relative to the surrounding marshes are affected by inundation extent and frequency. Thus, tree islands that are a meter or higher than the surrounding marsh tend to be inundated less frequently than those islands that are only 10–20 cm higher than the surrounding marsh. In terms of operations and restoration, the District needs to understand tree-island vulnerability in relation to hydrologic stresses associated with water management and climate (Sklar and van der Valk, 2002; Heisler et al, 2002). Thus, research efforts have been focused on tree islands located in areas where natural hydrology has been the most modified and in areas where the water regime would change with restoration efforts. For instance, evidence for the impacts associated with this type of hydrological heterogeneity can be found in the prolonged low water levels of northern WCA-3A **(Figure 9)** where extensive peat fires have removed all the organic soils (approx. 25 cm) from some islands making re-colonization by less water-tolerant tree species difficult, at best. At the other hydrological extreme, tree islands in southern WCA-2A and 3A are flooded for abnormally long periods of time **(Figure 9)** making the plant community more vulnerable to water stress and causing a decline in forest structure. Loss of tree islands in both number and size have been documented throughout the Everglades landscape over the last half of the 20th century, including a 61 percent and 87 percent decline of tree-island area in WCA-3 and WCA-2, respectively (Sklar and Van der Valk, 2002) and a decline in tree island number and size in impounded areas of WCA-1 (Brandt et al., 2000).

Past and Present Tree Island Elevation Responses to Hydrology

Project Overview and Background: In forested wetland environments, the processes of primary production, nutrient cycling and root decomposition are key factors that promote soil accretion and overall system stability (Wetzel et al., 2005; Cahoon et al., 2006; D'Alpos et al., 2007). Thus, to evaluate how soil accretion and elevation change are affected under different hydrological conditions detailed information on both aboveground and belowground processes is required. Furthermore, measurements of litterfall production and tree growth across varying hydrologic conditions are critical in resolving how aboveground production and nutrient cycling vary with hydrology (Barbour et al., 1987) and how these processes are linked to tree island health. Though rarely measured (e.g., Powell and Day, 1991; Megonigal et al., 1997; Grier et al., 1981), root production and turnover can contribute as much as half of the carbon cycled annually in forests (Vogt et al., 1998) and therefore cannot be ignored to better understand the mechanisms associated to soil formation and accretion (Baker et al., 2001; Cahoon et al., 2006). Research under this component will address three hypotheses: (a) differences in hydrologic regimes are primary explanatory variables of belowground dynamics; (b) trees in nutrient-poor environments will allocate more biomass to the belowground component; and (c) variation in above and belowground processes, together, may alter accretion and elevation.

To gain a longer-term perspective, however, paleoecological studies will provide evidence of the nature and sequence of environmental conditions conducive to tree island formation and resilience (Stone et al., 2002). For instance, recent studies carried out on fixed and strand tree islands point to the importance of drought cycles on tree island initiation and development over the last two millennia (Willard et al., 2006). Results from paleoecological studies indicate that tree islands formed under natural environmental change triggered by regional to global-scale climatic events, such as El Niño and the Little Ice Age (Willard et al., 2006). However, less well known is how resilient existing tree islands are under managed hydrologic conditions characterized by drainage, impoundment, and slower moving water (Willard et al., 2002). Based on a preliminary study conducted from tree island 3AS3 in August 2006 (Smoak and Gore, 2007), ^{210}Pb-dated profiles of ^{13}C and ^{15}N show the 1950s was a period of major changes in the tree island and slough habitat **(Figure 10)**; the timing of these changes coincident with the transition from drainage to impoundment in southern WCA-3A. In addition to quantifying responses of tree island vegetation and soil accretion to past and future hydrologic changes, paleoecological information will also enable researchers to consider legacies of past hydrologic and ecological conditions as a context for understanding *in situ* rates of production and decomposition, soil chemistry, and elevation changes observed at these islands. Thus, understanding the development and resilience of tree islands through both paleoecological and *in situ* approaches is critical to prevent, and possibly reverse, the reduction of tree islands since the 1950s, presumably the result of water management practices that influence tree island hydroperiods (Sklar and van der Valk, 2002).

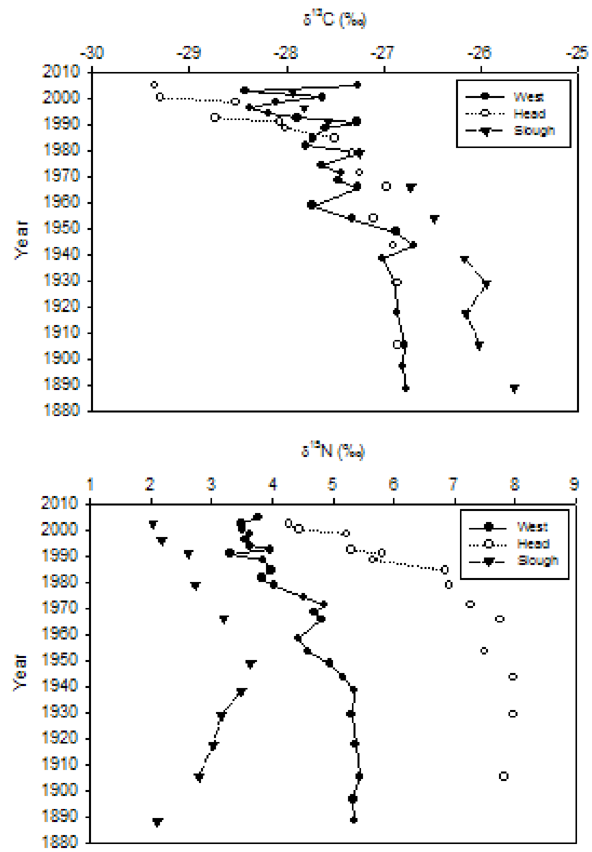

Figure 10. Stable isotope profiles of three sediment cores taken from tree island 3AS3.

Management and Restoration Objectives: The first set of objectives of this research includes (1) determining the spatial pattern and variability of litterfall; (2) defining the effects of water level variability on long-term patterns of litterfall production, phosphorus sequestration and nitrogen cycling; and (3) determining soil/peat accretion rates in relation to current water management practices and future predicted hydrologic restoration goals. Objectives 1–3 will provide a means to assess the ecological processes linked to tree island health and soil formation. Similarly these objectives will help to define where tree islands are more (or less) vulnerable to drowning and loss due to reduced productivity, lower rates of accretion, or greater sensitivity to water level variability. The second set of objectives utilize a paleoecological approach to (4) quantify vegetation changes in tree islands over the past 100–200 years; and (5) determine the hydrological conditions conducive to tree island formation, development, and maintenance. Objectives 4 and 5 will provide the pre-drainage variation in community types and soil development, essentially restoration targets for tree island health. These objectives complement the first three by providing a longer-term data set documenting tree island responses to hydrologic variation that occurred over several decades to centuries. Combined, accomplishing these objectives will provide the District with ecological and hydrological information that is suitable to maintaining or promoting tree island communities under different hydrological conditions.

Methodological Approach: To understand short-term and long-term processes in tree islands, researchers will employ a combination of *in situ* measurements of ecosystem functions (e.g., production, decomposition, accretion) and paleoecological analyses (e.g., soil profiles of plant and animal fossils). Together, these data provide researchers with a mechanistic understanding of the tree island responses to hydrology. Importantly, this combination addresses both short-term responses (season to yearly, via monitoring) and long-term responses (decades to centuries, via paleoecology analyses), matching the timescales relevant to the pace of adaptive management and restoration activities. Paleoecological research at tree island sites will be used to develop independent proxies of hydroperiod using fossil animal material (Smoak and Gore, 2007) and of vegetation changes using plant-derived material (Saunders et al., 2006; Willard et al., 2006). These data will help confirm and interpret the hypotheses relating tree island vegetation changes to local and regional hydrologic conditions and resolve how these systems may respond, positively or negatively, to future restoration measures. The combined paleo-inferred changes in vegetation, hydrology, and soil accretion will be compared with hydrologic records (i.e., water stage data), with historic hydrology hindcasted by the South Florida Water Management Model Version 3.5, and with paleo-climate data that captures regional precipitation over the past several centuries (Willard et al., 2006).

Application of Results: In the Everglades, where inorganic sediment input is scarce, belowground peat production is the primary process that control soil accretion. Thus, understanding how current hydrological conditions are affecting aboveground and belowground processes on tree islands are key factors to better mange the system to promote soil formation and accretion. The key to successful management and restoration of tree islands relies on our understanding of the processes that control elevation change (i.e., peat accumulation and organic matter decomposition) in relation to past and future hydrologic regimes (i.e., flow rates, depths, and hydroperiods). Estimation of both aboveground and belowground processes and fine-root production in particular, will help to determine the processes that lead to soil formation and elevation sustainability. Such processes represent the primary sources of energy and nutrient flow through forested systems; particularly for those systems that are subject to periodic disturbances that increase the frequency and extent of fine root turnover. In addition, quantifying long-term changes historically, through paleoecological analyses, will help to understand how tree islands may respond to restoration measures. Importantly, these analyses will resolve the degree to which restoring the original ridge-and-slough landscape can also maintain productive and stable tree island communities.

Tree Island Development and Sustainability: Synoptic Studies and LILA Experiments

Project Overview and Background: Forest structure, regeneration and recruitment of native tree woody species on tree islands need to be studied in order to understand how the plant community is responding to current hydrological conditions. This information will allow better management of the hydrological system for ridge and slough, while preserving tree islands. It is hypothesized that the current hydropatterns in the southern portion of the Everglades are negatively affecting species composition and forest structure by promoting the establishment of water-tolerant indigenous woody species and restricting the regeneration and recruitment of hardwood woody species on tree islands. This encroachment of water-tolerant woody species is creating a shift in island-species composition from indigenous upland/hammock species to more water-tolerant species—therefore reducing woody tree-species diversity. A synoptic program to document tree island status, development, and sustainability is aimed at establishing base-line conditions and performance targets for CERP. Nested within these components are five lines of research designed to explore how the plant communities on tree islands are responding to current and predicted future hydrological conditions. These include: (1) tree island formation; (2) tree island health; (3) distribution and abundance of woody species; and 4) above and belowground processes.

The restoration of the Everglades will require restoring tree islands where they have been lost and possibly creating tree islands to mitigate for losses. Research designed to assess tree island restoration techniques is an essential first step for developing these protocols. An experimental program to document tree island vegetation and biogeochemical processes in relation to flow and depth patterns will be evaluated in the LILA research facility **(see Figure 6)**. LILA acts as a bridge between the results of small-scale microcosm experiments and large-scale synoptic monitoring and research. LILA does not replace monitoring or research in the natural system. It supplements monitoring, reduces experimental variance, and decreases field costs by effectively linking hydrology (flow, seasonal water level fluctuations) with the hypotheses introduced at the beginning of this section.

Management and Restoration Objectives: The objectives of the tree island synoptic program are: (1) to determine how tree islands developed over the past century under differing hydrological conditions; (2) to define patterns of forest structure on tree islands based upon physical characteristics (peat depth, hydrology, nutrients); (3) to evaluate tree island seedling recruitment as an indicator of ecological health; and (4) to monitor and track changes in tree island structure over time as physical gradients are altered due to CERP implementation and operational modification.

The LILA experimental component includes four main objectives; (1) assess the flooding tolerances of trees, (2) evaluate competitive interactions and the spacing tolerance of tree species as a function of hydroperiod, (3) determine the role of sheetflow and water velocity on tree island development, and (4) explore the role of the ground water–surface water interactions on tree physiology and island geomorphology. Tree islands studies at LILA are designed to provide restoration managers with reliable and cost-effective methods for tree island restoration and creation, as well as a better understanding of how tree island habitat is influenced by hydrology. One hypothesis regarding tree island development states that when woody shrubs become established during dry conditions, they create a root system that elevates the land. The subsequent increased growth of plants and subsequent accumulation of organic soil, in turns, elevates the wetland further, increasing the size of the tree island habitat until some dynamic equilibrium is reached between soil oxidation and peat decomposition.

Methodological Approach: CERP is expected to produce large-scale changes in the current hydrologic nature of the system. To evaluate impacts and determine species composition, forest structure, regeneration, and recruitment, the synoptic studies will establish permanent sampling plots on the heads and near-tails of representative tree islands. Data collected from these large sample plots will give a thorough representation of vegetation structure and will facilitate the evaluation of long-term cumulative impacts. Included in this approach is an inventory for old world climbing fern (*Lygodium microphyllum*) in WCA-3A and WCA-3B began in 2006 with the ultimate goal of surveying tree islands to determine the distribution and abundance of this easily spread invasive fern.

Experiments conducted at LILA follow a similar approach, in which environmental factors associated to regeneration, recruitment, and competition will be clearly defined by planting saplings in different densities and in a randomized pattern to examine the influence of distance to and the identity of neighboring trees on island. Similarly, plant physiology techniques, such as sap flow, stem water potential, CO^2 uptake and water lost on selected tree islands and species, will be used to determine tree island health and stressors. Specifically, these are the four principle LILA tree island investigations:

- **Flooding tolerances of trees:** Tree species on islands occur along elevation gradients, presumably because of differences in flooding tolerances. However, flooding tolerances of most common tree island trees are not well known. Measurements include plant structure, survivorship, water conductance, and productivity using allometric equations.
- **Competition and spacing tolerance of trees:** Apart from hydrology, other environmental factors have an influence on the structure of tree islands and the success or survival of tree island tree species.
- **Effect of water velocity on tree island development:** Flow patterns clearly influence the teardrop shape and dynamics of fixed tree islands in the Everglades. Understanding how flow effects the development of fixed tree islands has important implications for evaluating CERP projects and for designing created tree islands and restoration projects.
- **Ground water–surface water interactions:** The importance of groundwater–surface water interactions in relation to maintaining tree islands is completely unknown. LILA is the perfect logistical environment for carefully exploring and testing hypotheses related to nutrient focusing, nutrient upwelling, and nutrient rock mining by tree roots.

Application of Results: Although the loss of tree islands has been attributed to hydrologic changes, experimental evidence that provides a sound understanding of basic tree island ecology and restoration protocols are lacking. Most important, the hydrologic parameters necessary for tree island restoration are the least understood and quantified components of Everglades restoration. With their extreme sensitivity to water levels, the health of tree islands can be a good indicator for the overall condition and success of hydrological management of the Everglades. The LILA tree island projects will provide basic understanding of ecological interactions at the macro scale. The synoptic surveys will determining the causal background of the structure of vegetation, including the spread of old world climbing fern through long-term field research and monitoring before and during the CERP; thus, allowing the SFWMD to make adjustments in hydrology to ensure tree island persistence. Synoptic tree island assessments will be used in the implementation and evaluation of Modified Water Deliveries, CSOP, RECOVER and the CERP DECOMP. It also has relevance for water management as specified by the Florida Everglades Forever Act of 1994; and by Section 373.042(1) of the Florida Statutes requiring water management districts to establish MFLs.

Exotics on Tree Islands: *Lygodium microphyllum* impacts and control

Project Overview and Background: In South Florida, invasive plants have invoked tremendous ecological, environmental, and economical damages to various local habitats and natural systems (forests, wetlands, aquatics, parks, etc.). Of particular concern is that old world climbing fern (*Lygodium microphyllum*) is invading at an alarming rate. It is the fourth most invasive plant in South Florida and ranked Category 1 by the Florida Exotic Pest Plan (Langeland, 1998). From 1993 to 2003, the fern expanded from about 30,000 acres to 150,000 acres. At this expansion rate, almost every habitat south of Lake Okeechobee will be infested with the fern by 2009 (Clarke et al., 2006). *L. microphyllum* could have a lasting ecological impact on the wetland ecosystem of the Everglades and jeopardize the $8.4 billion Everglades restoration program.

Old world climbing fern is an exotic twining fern that originated from the old world tropics (Wagner and Smith, 1993). The vine-like leaves wrap around trees, shrubs, grass and often extend to the top and then cascade downwards. Its sporophytes and gametophytes actively grow year-round. Various control methods, including herbicide, burn, and mechanical removal, have been applied, but little progress has been made.

A major campaign to control establishment and spread of exotic invasive plant species in the A.R.M. Loxahatchee National Wildlife Refuge (LNWR) is currently being sponsored by the FDEP. Native plant and associated wildlife communities which have been negatively affected by the invasive exotic plants (habitat degradation) are expected to recover following exotic species being controlled. However, the eradication program is being conducted without a parallel assessment of the intended benefits of this activity. Monitoring is needed to quantify the response of the native species abundance and diversity. The development of an autonomous bioacoustic network would provide quantitative metrics of avian and herpetological species on tree islands in the LNWR.

Management and Restoration Objectives: The main objective of the proposed research targets *L. microphyllum* control and management focusing on two major research components: (1) a controlled experimental approach to evaluate forms of biocontrol; and (2) synoptic field surveys in WCA-1 to provide quantitative metrics of avian and herpetological species responses to the control of this invasive.

Methodological Approach: Biocontrol of *L. microphyllum* is still in its infancy. Classical biocontrol research, currently conducted by the USDA, uses introduced natural enemies (DeBach, 1974). This research will be supplemented by the District's investigation into soil fungus control (Clarke et al., 2006). The District will examine the effectiveness of soil fungus agents and molecular mechanisms for *L. microphyllum* control by conducting small-scale field applications and risk assessments.

The avian and herpetological field assessments for the early eradication of *L. microphyllum* will include: (1) a coordinated set of surveys to identify the status of habitats currently invaded by *L. microphyllum*; (2) a determination of the spatial distribution of this species; and (3) the development of a spatial database for *L. microphyllum* inventory.

In terms of the first assessment, sampling protocols for highly mobile species have often relied upon highly trained biologists who visually observe or detect the presence of a species indirectly by listening to their vocalizations. This approach is subject to biases associated with observer skills and weather conditions, and is limited by expensive labor requirements. Autonomous bioacoustic sensing represents an alternative approach to assessing species presence. Small computers equipped with microphones and sound recording software has enhanced the extent and breadth of wildlife surveys by allowing for FTP transmission of sound recordings from field-deployed equipment to the laboratory where the analysis and interpretation of auditory signals are processed.

Application of Results: The results of this research and inventory will be utilized by natural resource management agencies to develop an early-stage treatment and removal plan for old world climbing fern. And, currently there is a gap in knowledge regarding the wildlife composition of tree islands and the seasonal spatial distribution of numerous avian populations across the Everglades. Mapping wildlife distributions allows for more of a systems level understanding of landscape change due to *Lygodium*. Sonograms of individual species will be collected and archived in a sound library and this library will develop further as the bioacoustic network expands into regions that need new hydrologic management or water quality improvements.

MANGROVE STRUCTURE AND FUNCTION

A brackish water ecotone of coastal bays and lakes, mangrove and buttonwood forests, salt marshes, tidal creeks, and upland hammocks separates Florida Bay from the freshwater Everglades. The 24 km-wide ecotone adjoins the north shoreline of Florida Bay and the Gulf of Mexico. The model boundary from Highway Creek (U.S. 1) west to Lostman's River delineates the interface of Florida Bay and the Gulf of Mexico that is affected by freshwater flows from the Everglades. The mangrove estuary transition is characterized by a salinity gradient and mosaic that vary spatially with topography and that vary seasonally and inter-annually with rainfall and freshwater flow from the Everglades. Because of its location at the lower end of the Everglades drainage basin, the mangrove estuary transition zone is potentially affected by upstream water management practices that alter the freshwater heads and flows that drive salinity gradients.

The mangrove estuarine transition zone is the product of an interplay of marine and freshwater influences that dominate every aspect of the system as external drivers and ecological stressors. The controlling marine influence is sea level. There is strong evidence that present rates of sea level rise in South Florida, which are attributed to global climate change, will massively re-configure the geomorphology, circulation patterns, salinity patterns, and ecological processes of the mangrove estuarine transition zone during the 21st century (Wanless et al., 1994). The controlling freshwater influence is flow from the Everglades. The construction and operation of South Florida's water management system during the 20th century has depleted freshwater flow to the estuary and has altered its timing and distribution (VanZee, 1999; McIvor et al., 1994). Ecological patterns and processes in the mangrove estuary are closely linked to patterns of hydrology and salinity that have been altered by reduced freshwater flow. Declines in many ecological attributes of the estuary correspond to the early development of the water management system.

Mangrove forests (*Rhizophora, Avicennia, Laguncularia*, and *Conocarpus*) dominate the primary productivity and soil accretion within the estuarine transition zone (Childers et al., 1999). That productivity appears to reflect the nutrient status of the estuarine interface, which is related to the mixing of water from the Everglades with that from the Gulf of Mexico and Florida Bay. The mosaic of mangrove forests and associated plant communities, documented by (Welsh et al., 1995), defines the habitats of the mangrove estuarine transition zone. The spatial distribution of those habitats, in combination with the salinity gradient that overlays them, determines the suitability of this region to sustain its faunal attributes (Browder and Moore, 1981).

Embedded within the mangrove forests are tidal creeks and adjacent salt marshes, upland tropical hardwood hammocks, halophytic prairies, and coastal lakes. At the landward interface of the estuarine transition with Everglades marl wetlands, a "white zone" band of sparse, relatively unproductive, mixed mangrove and graminoid vegetation is considered an indicator of the balance between freshwater flow and sea level rise (Ross et al., in press). Working hypotheses relate the distribution and persistence of each of these plant communities to one or more of the stressors that have been identified for the mangrove estuarine transition zone.

Freshwater Flow Effects on the Mangrove Transition Zone

Project Overview and Background: The mangrove transition zone is an expansive ecotone between the Everglades and the coastal and estuarine ecosystems of Florida Bay and southwest Florida. The importance of the transition zone related to current water management practices and restoration efforts in CERP are detailed in a recent ecological conceptual model (Davis et al., 2005). This zone is ecologically important and highly sensitive to water management. The mangrove wetlands filter and retain nutrients derived from the Everglades and coastal systems and support high primary productivity rates (Childers et al., 2006) and critical habitat structure. This productivity and vegetative structure of mangrove forests, ponds, and creeks of this zone support many animal species, including a forage base for wading birds such as the roseate spoonbill (see the *Wildlife Biology to Food Web Ecology* section of this appendix). This zone is also the home of the endangered American Crocodile.

With historic diversion of fresh water away from Florida Bay and Whitewater Bay and sea level rise, the salinity transition zone has become wider and saltier. In the southeast Everglades, there has been an expansion of a low productivity "white zone" over the past 50 years, with northward movement of sparse, scrub mangroves into areas that previously were the lower Everglades, dominated by productive periphyton mats. Potentially counteracting sea level rise, soil accretion is a key factor affecting the extent and distribution of future coastal transgression and associated changes in landscape pattern in the transition zone (Davis et al., 2005). This research plan proposes to address these issues includes documenting changes in landscape patterns in relation to hydrologic conditions (including salinity), measuring rates of soil accretion and factors that influence accretion processes, and synthesizing the results through ecological modeling.

Management and Restoration Objectives: Major objectives for water management projects' effects on mangrove transition zone are to prevent harm to this region via increased salinity magnitude, duration, and spatial extent of salinity intrusion; reverse this intrusion to the extent possible in the face of sea-level rise; and sustain diverse habitat (e.g., SAV in coastal ponds) and animal populations that depend on this habitat (especially wading birds, water fowl, and crocodiles). Protection of nearby water supply (e.g., the Homestead well field) from saltwater intrusion is also a primary District mission. Objectives of our monitoring, research, and modeling are to provide a basis for quantifying the hydrologic needs of this region with regard to the above management interests, documenting: (1) the status and trends of the transition zone's hydrologic condition (especially salinity) and ecosystem structure (landscape patterns of vegetation zones, including the "white zone"); and (2) measuring and mechanistically understanding changes in soil elevation such that the District builds a capability to forecast the consequences of alternative water management plans.

Methodological Approach: This project will use a combination of large-scale mapping of landscape patterns (based on aerial photographs or remote sensing) and finer scale gradient analyses that follow the Coastal Gradient design specified in the RECOVER Monitoring and Assessment Plan. Gradient analyses will include fine scale mapping of salinity along and below creeks and rivers (with Dataflow and resistivity surveys; Madden and Day, 1992; Swarzenski, 2006) that flow through the transition zone, measurement of water flux, local surveys of plant community structure and status of the forage fish base (see the *Food Web* section of this appendix), and a strong focus on soil accretion rates and associated processes. This latter focus will include the measurement of soil elevation and accretion or loss (using sedimentation-erosion tables; Boumans and Day, 1993) and (Cahoon et al., 2002a,b), litter fall, root production, and detrital decomposition rates. Synthesis through modeling will include hydrologic models of major creeks and rivers (starting with the Taylor Slough and Creek system) combined with biogeochemical and mangrove ecological models (e.g., the HYMAN, NUMAN, and FORMAN models of Chen and Twilley, 1998; and Twilley and Chen, 1998; see the *Synthesis and Integration* section of this appendix).

Application of Results: Results from this project will be applied to future updates and modifications of Everglades and Florida MFLs as specified in the Florida Bay MFL Prevention Strategy (SFWMD, 2007), operational planning (particularly with regard to CSOP), and to provide a baseline and benefits analysis for restoration projects (C-111 Spreader Canal and DECOMP). Assessment of hydrologic and ecologic change in the mangrove transition zone is also an essential part of Greater Everglades Module analysis within RECOVER. For MFLs, the potential for soil loss through oxidation is the lynchpin of the Everglades MFL Rule, while salinity stress on mangrove zone SAV is the lynchpin of the Florida Bay MFL Rule. Results from the proposed transition zone work here will provide an improved scientific foundation on which future rule revisions can be based. Performance measures within CSOP and CERP explicitly define the need for much of the information proposed to be provided here, including salinity distributions, white zone and other vegetation zone shifts, and soil elevation changes. Understanding and forecasting the effects of sea-level rise is critical for CERP. This project will be a primary mechanism to provide such information.

SYNTHESIS

The Everglades Division will not propose a separate modeling initiative for two reasons: (1) District policy and approach has stipulated that hydrological and ecological modeling programs need to be components of the Interagency Modeling Center (IMC); and (2) stand-alone modeling programs run a high risk of failure due to poor integration with synoptic and experimental programs. For these reasons all the modeling approaches that the District has and will initiate are designed to be closely integrated with field and experimental data, and have already been presented within earlier sections of this appendix. It should be noted that these models are not also being developed by the IMC. We are in frequent communication with the IMC because we use, review, and recommend changes to IMC on a regular basis.

The one stand-alone synthesis program that is included as part of this strategic plan, may take the Everglades Division and possibly the SFWMD down a new project evaluation road by exploring new evaluation tools in the field of ecological economics and ecosystem services. Much of the science in our Division plan is designed to examine indirect effects, feedback loops, and habitat stability, in relation to water management scenarios and restoration designs. These are difficult concepts to capture in the more classical cost-benefit analyses that are currently prevalent.

Ecological Valuation

Project Overview and Background: New holistic techniques, designed to integrate socio-economic drivers of environmental change with ecological drivers of biodiversity and productivity, have given rise to the field of ecological economics in the business world and the field of ecosystem services in the environmental world (De Groot et al., 2002). Every regulation change in the Everglades and every CERP project requires an analysis of alternative plans and operations. These alternatives are judged by an outdated system of costs and benefits that try to incorporate our understanding of Everglades structure, but which do a poor job of incorporating ecosystem function (Light, personal communication). These analyses misrepresent the long-term or large-scale ecosystem services needed by society (Costanza et al., 1997; Farber et al., 2002).

As a result of a decade or more of ecological investigation in the Everglades, comparative ecological economic analysis is not only possible, it is essential to a comprehensive assessment of ecosystem functions, goods and services. Once this is understood, the human systems will be better able to operate the water management system through restoration actions and regulatory policy (**Figure 11**) at a variety of scales.

Management and Restoration Objectives: The goal of this project is to provide the District with a set of environmental evaluation tools that are comprehensive and representative of the ecosystem and monetary functions that are associated with the Everglades.

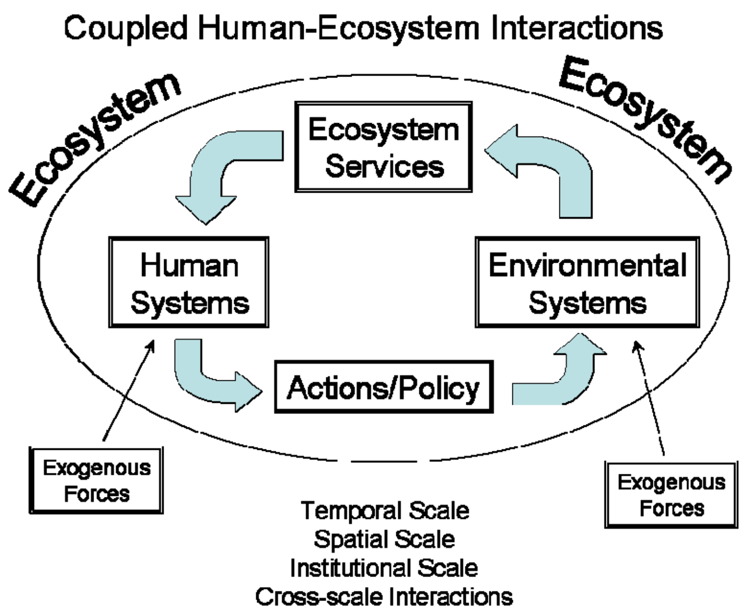

Figure 11. The nesting of both environmental systems and human systems within the South Florida ecosystem indicates that effective resource management will be helped by knowing the value of ecosystem services.

Methods and Procedures: Ecosystem valuation techniques have never been applied to the Everglades and thus, there will first need to be a comparison and an analysis of the strengths, weakness, and complexities associated with a variety of valuation approaches. These will include, but not limited to the Regulatory, Habitat, Production and Information functions as described by DeGroot et al. (2002), the direct market, indirect market, contingent, and group valuation as described by Farber et al. (2002), the carbon-based biophysical methods of Costanza et al. (1997), and the thermodynamic energy approach of (H.T. Odum, 1996). After this comparative study, a subset of these valuation techniques will be applied to a CERP project such as the Florida Bay Feasibility Study or the WCA-3 Compartmentalization project.

Application of Results: Large scale restoration programs are often very expensive and as a result do not get fully implemented because classical cost-benefit analyses fail to capture ecosystem functions, goods and services. Major restoration programs such as, Decompartmentalization of WCA-3 continue to hit road blocks and delays because the benefits of the ecosystem functions have not been calculated. The transformation of ecological data into economic parameters will support efficient restoration planning. These new techniques will be used to better select restoration and operational plans that are sustainable and cost effective because the nature of the trade-offs are captured and mitigated.

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ACKNOWLEDGEMENTS AND ENDNOTES

Table of Organization of the Everglades Division
(September 2007)

Director: Seán Sculley	Sr. Admin. Assist.: Brenda Valente	Financial Officer: Lori Wenkert	Chief Scientist: Fred Sklar
Landscape Processes	Marsh Ecology Research Group	Landscape Analysis, Mapping & Data Automation	Florida Bay Group
Sr. Supervising Scientist: Shili Miao	Sr. Supervising Scientist: Sue Newman	Sr. Supervising Scientist: Tom Dreschel	Sr. Supervising Scientist: Dave Rudnick
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	Michael Manna	Ken Rutchey	
	Robert Shuford	Colin Saunders	
		Ted Schall	

[1]**RECOVER hypotheses** (except where noted) that are referenced in **Table 1** and presented throughout the Everglades Strategic Research Plan.

Hypothesis 1: Wading Bird Nesting Colony Location, Size, and Timing

Hypothesis 2: Wading Bird Super Colony Formation

Hypothesis 3: Aquatic Fauna Dry and Wet Season Prey Concentration

Hypothesis 4: Linkage of Periphyton to Higher Trophic Levels

Hypothesis 5: Florida Bay Faunal Responses and Nursery Function Hypotheses

Hypothesis 6: Plant Community Dynamics along Elevation Gradients

Hypothesis 7: Nutrient Inputs and Sheet Flow as Determinants of Wetland Nutrient State in the Everglades

Hypothesis 8: Everglades Ridge and Slough Microtopography and Landscape Pattern in Relation to Organic Soil Accretion and Loss

Hypothesis 9: Sea Level and Freshwater Flow as Determinants of Coastal Transgression

Hypothesis 10: Sea Level and Freshwater Flow as Determinants of Production, Organic Soil Accretion, and Resilience of Coastal Mangrove Forests

Hypothesis 11: Florida Bay Water Quality

Hypothesis 12: Florida Bay Submersed Aquatic Vegetation

Hypothesis 13: Rainfall and Sheet Flow as Determinants of Natural System Hydrologic Characteristics in the Everglades

LTP Hypothesis 1: External Disturbances are Essential to Restoring Structure and Function in Nutrient Enriched Areas of the Everglades