SOUTH FLORIDA ECOSYSTEM RESTORATION:

SCIENTIFIC INFORMATION NEEDS

A Science Subgroup Report

to the

Working Group

of the

South Florida

Ecosystem Restoration Task Force

1996

SCIENCE SUBGROUP

OTHER FEDERAL CONTRIBUTORS

Tom Armentano, NPS/ENP
Joan Browder, NOAA/NMFS
Bradford Brown, NOAA/NMFS, Co-chair
Gary Buckingham, USDA/ARS
Lawrence Burns*, EPA
Michael Crosby, NOAA/NOS
Kenneth Cummins, SFWMD
Truman Duncan, Miccosukee Tribe
Barry Glaz, USDA/ARS
Robert Halley, USGS
James Harriman, BIA
Lorraine Heisler, FGFWFC
Greg Hendricks, USDA/NRCS
Aaron Higer, USGS
Ronald Hilton, COE
Wiley Kitchens, USGS/BRD
Leo Minasian, FDEP
Douglas Morrison*, FWS
John Ogden, SFWMD
Peter Ortner, NOAA/OAR
Robert Pace, FWS
Mary Ann Poole, FGFWFC, Co-chair
Dan Scheidt, EPA
Hanley Smith, COE
Craig Tepper, Seminole Tribe
Michael Troyer, EPA
James Weaver, USGS/BRD, Co-chair

*Former SSG member integral to preparation of this report.

OTHER FEDERAL CONTRIBUTORS

Robert Ambrose, EPA
Rochelle Araujo, EPA
M. Craig Barber, EPA
Russell Bullock, EPA
Robert Fennema, NPS/ENP
Carole Goodyear, NOAA/NMFS
John Klein, NOAA/NOS
John Kucklick, NOAA/NMFS
Elmar Kurzbach, COE
William Loftus, USGS/BRD
Nicholas Loux, EPA
Mark Powell, NOAA/OAR
Patricia Richards, FWS
Michael Robblee, USGS/BRD
William Robertson, USGS/BRD
James Snyder, USGS/BRD
Michael Soukup, NPS
Nancy Thompson, NOAA/NMFS

EDITOR

Carole Goodyear, NOAA/NMFS

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EXECUTIVE SUMMARY

This report on information needs is the first step in development of an ecosystem-based South Florida Comprehensive Science Plan required for the ecosystem approach mandated by the Interagency Task Force in its September 23, 1993, Agreement on South Florida Ecosystem Restoration. The modeling, monitoring, and special studies recommended in this document will provide the information basis for ecosystem management.

South Florida is a heterogeneous system of wetlands, uplands, and coastal and marine areas comprising at least 11 major physiographic provinces. It is dominated by the watersheds of the Kissimmee River, Lake Okeechobee, and the Everglades. Prior to drainage, wetlands covered most of central and southern Florida. Productivity of the predrainage wetlands was dependent on dynamic hydrologic storage and sheetflow, large spatial scale, and heterogeneity in habitat. The biological abundance and diversity the habitats once supported were maintained by the complex annual and long-term hydrologic patterns of the natural system, over which were superimposed sporadic events such as storms, fires, and freezes.

Human alterations in the hydrologic system beginning in the late 1800s have created water quality and water quantity problems for South Florida's natural systems, including the Everglades and the estuaries. Hydroperiods and hydropatterns, which relate to the duration, timing, and extent that wetlands are wet, have been greatly distorted. The quantity, timing, location, and quality of freshwater flow to estuaries have been greatly modified. The pace of deterioration seems to be increasing. Known wildlife populations are now a fraction of their size of even 30 years ago. Florida Bay is experiencing obvious catastrophic change manifested in massive seagrass dieoffs and noxious algal blooms. Even the reef tract is not immune to probable land-based detrimental influences.

South Florida's human population currently exceeds 5 million and is expanding rapidly. This expanding human presence has dramatically changed the South Florida Ecosystem. In addition to hydrologic alterations for flood control, the changes include an increasing water demand by agricultural and urban uses, while, at the same time, the water supply has actually been decreased by the conversion of land to agricultural and urban uses and by the shunting to the coast of fresh water that previously was stored in the wetlands, the soils, and the aquifers. Other changes are water quality and treatment problems, soil subsidence in the Everglades Agricultural Area, nutrient enrichment, pollution by contaminants, introduction of invasive non-native plants and animals, fragmentation of habitats and landscapes, loss of wetland areas and functions, altered fire regimes, and declines in reef and estuarine resources.

The problems of nonindigenous species, mercury contamination, pollution by pesticides and other contaminants, and preservation of endangered species are so serious and pervasive throughout South Florida that individual chapters are devoted to these cross-cutting problems on a region-wide basis, in addition to discussions in most of the subregion chapters. Holistic solutions to these problems will provide for more sustainable economic opportunities while at the same time improve the sustainability of the natural portions of the South Florida Ecosystem.

The overall goal of the restoration effort is to restore a sustainable ecosystem that preserves the valued properties of South Florida's natural systems and supports productive agriculture-, fishery-, and tourist-based economies and a high quality of urban life. The basic premise is that better water management will provide sustainability across both human and natural systems. Therefore, the working hypothesis is that hydrologic restoration is the prerequisite to ecosystem restoration. The highest priority science is that which determines how to modify the structure and operation of the hydrologic system to accomplish restoration.

The overall objective of the Science Subgroup is to develop an interagency, interdisciplinary science program that will guide restoration actions by determining relationships between ecosystem function and hydrologic regime and describing hydrologic conditions required to support the characteristic landscapes, biodiversity, and wildlife abundance of predrainage South Florida. The information needs presented in this document are directed at obtaining the data required to provide a scientific basis for management decisions and the information that could lead to increased beneficial interactions between natural and human communities.

The scientific investigations identified in this report are directed at characterizing the predrainage system, particularly its hydrology, and comparing it to the present system; determining the key characteristics of the former natural hydrologic system that supported the rich diversity and abundance of wildlife that have been lost; designing structural and operational modifications of the C&SF Project that would recreate the key characteristics of the natural hydrologic system; assessing the hydrologic and ecological results of these modifications; and modifying the design to make improvements. Particularly appropriate is the adaptive management approach, in which the measured outcome of management actions is used to make corrections and adjustments in those actions in order to improve the probability of achieving objectives. Adaptive management has three elements -- models, restoration support studies, and monitoring -- that must be used as coordinated, supportive tools. The operational foundation of the adaptive management approach is periodic environmental assessment, which utilizes models to predict outcomes, monitoring to test the predictions, and field and laboratory studies to provide critical supporting information.

The scientific information needs in relation to the restoration goal and the restoration and science objectives for the South Florida Region, each of the 10 geographic subregions, and each region-wide topic are summarized in the following figures. The many information needs reflect the diversity of habitats and biotic communities within South Florida -- and also the diversity of ecological problems.

THE REGIONAL ECOSYSTEM

INTRODUCTION

The South Florida Ecosystem, as defined by the Science Subgroup (SSG 1993), covers the area within the jurisdiction of the South Florida Water Management District. It includes coastal waters and islands, including Florida Bay, Biscayne Bay, and other estuaries and the Florida Keys and reef tract to the Dry Tortugas. The South Florida Ecosystem encompasses an area of approximately 28,000 km^2 (10,800 mi^2) comprising at least 11 major physiographic provinces. These include the Kissimmee River Valley, Lake Okeechobee, the Immokalee Rise, the Big Cypress, the Everglades, Florida Bay, the Atlantic Coastal Ridge, Biscayne Bay, the Florida Keys, the Florida reef tract, and nearshore coastal waters.

BACKGROUND

South Florida is a heterogeneous system of wetlands, uplands, and coastal and marine areas, dominated by the watersheds of the Kissimmee River, Lake Okeechobee, and the Everglades. Prior to drainage, wetlands covered most of central and southern Florida. Wetland landscapes included swamp forests; sawgrass plains; mosaics of sawgrass, tree islands, and ponds; marl-forming prairies dominated by periphyton; wet prairies dominated by *Eleocharis* and *Nymphaea*; freshwater marshes; saltwater marshes; cypress strands; and a vast lake-river system draining into Lake Okeechobee. Elevated areas that seldom were inundated supported pine flatwoods, pine rocklands, scrub, tropical hardwood hammocks, and xeric hammocks dominated by oaks. The natural seascapes of South Florida consisted of riverine and fringe mangrove forests, beaches and dunes, seagrass beds, intertidal flats, mud banks, hardbottom communities, coral reefs, and open, inshore shallows. These habitats were interconnected on an extremely low topographic gradient of 2.8 cm/km (1.8 in/mi) in which elevations ranged from about 6 m (20 ft) at Lake Okeechobee to below sea level at Florida Bay.

The biological abundance and diversity these habitats once supported were maintained by the complex annual and long-term hydrologic patterns of the natural system, as expressed in wet-dry cycles, rates of expansion and contraction of water area, surface water and water depth patterns, annual hydroperiods, flow volumes, and, at the coast, salinity and mixing patterns. Superimposed over the periodic changes were sporadic events such as storms, fires, and freezes, which helped to establish and maintain habitat heterogeneity. Productivity of the predrainage wetlands of South Florida was dependent on:

> **Dynamic hydrologic storage and sheetflow.** Contributing to dynamic storage were the very shallow elevation gradient, vast expanses of emergent vegetation, thick peat substrates, sand hills, and highly permeable limestones. Water masses were constantly progressing downslope but so slowly that, in effect, water was banked during one season to use in another. Transport varied between structural elements from on the order of months to years. Throughout the system, groundwater seepage driven by hydraulic gradients provided the base flow of creeks, rivers, and possibly even surface runoff across the mangrove zone. The extended hydroperiods of the natural system depended more on the large dynamic storage capacity and delayed flow-through than on the immediate effects of rainfall. Because of the dynamic storage and slow rate of water flow throughout the natural system, wet season rainfall kept the wetlands flooded and maintained freshwater flow to the estuaries well into the dry season. This carry-over effect was so great that a year of high rainfall maintained surface water in wetlands and freshwater flow to estuaries even into one (Walters et al. 1992; Fennema et al. 1994) or more (Browder 1976) subsequent drought years. The dynamic storage made wetlands and estuaries less vulnerable to South Florida's spatially and temporally variable rainfall.

> **Large spatial scale.** The vastness of the predrainage wetland made it possible for the natural ecosystem to support genetically viable numbers and subpopulations of species with large feeding ranges or narrow habitat requirements, provide the aquatic production to support large numbers of higher vertebrate animals in a naturally nutrient-poor environment, and sustain habitat diversity through natural disturbance (DeAngelis 1994; DeAngelis and White 1994). Population resiliency was undoubtedly proportional to the extent of these wetlands because habitat

diversity, number of seasonal refugia, and number of dispersal options are proportional to wetland area. The same is true of other habitat types, such as the pinelands, which extended for vast distances.

> **Heterogeneity in habitat.** Habitat heterogeneity was a major contributor to biotic diversity and the persistence of populations (DeAngelis 1994; DeAngelis and White 1994). The vegetative landscape resulting from the vast, low-relief, low-gradient landform was a diverse mosaic of plant communities that varied in extent from patches on the order of tens of meters to areas approaching physiographic provinces. Heterogeneity was maintained by micro-topographic features, small-scale climatic variation, and natural disturbances such as freezes, fire, and storms, acting on the large spatial scale (DeAngelis 1994). The mosaic of habitat types and water depths provided the spatial framework for production and survival of animals under a wide seasonal and annual range of hydrologic conditions.

South Florida is home to two federally recognized Indian tribes, the Seminoles and the Miccosukees, whose reservations are an integral part of the ecosystem. Native Americans have inhabited southern Florida for at least 10,000 years, predating formation of the "Everglades" by about 5000 years (Carr and Beriault 1984). The modern Seminoles and Miccosukees in the Everglades began establishing their populations (collectively as Seminoles) circa 1720 (Paige and Vanhorn 1982). The historical presence of Native Americans can be regarded as part of the natural ecosystem (Lodge 1994). The Miccosukee and Seminole Tribes of Florida became Federally recognized in 1962 and 1957, respectively, and their reservations became Federal trust lands to be held in trust for the tribes, their resources protected by the Federal Government. Today, approximately 462,000 acres of land in South Florida are considered Indian lands. This includes much of WCA 3A, which is perpetually leased by the State of Florida to the Miccosukee Tribe. The traditional and modern lifestyles of approximately 2500 tribal members are dependent on fulfillment of the Federal Government's trust responsibility to protect their lands, resources, and use rights.

MAJOR ISSUES

Water quality and water quantity problems for South Florida's natural systems, including the Everglades and estuaries, have resulted from man-made changes in the hydrologic system. These changes began before the turn of the century with dredging that channelized the Caloosahatchee River and connected it to Lake Okeechobee. With increasing population growth after 1900 came massive modification of the natural system. Changes in the hydrologic structure of South Florida culminated in creation and implementation of the C&SF Project in 1948. The enabling legislation gave the COE responsibility for construction and oversight of water management structures throughout the Kissimmee-Okeechobee-Everglades basin. In 1949, the State created the Central and Southern Florida Flood Control District, which has since become the SFWMD. Project purposes were: 1) flood control; 2) drainage; 3) water supply (municipal, industrial, and agricultural); 4) protection against salt water intrusion; 5) preservation of fish and wildlife resources in the Everglades; 6) water supply to ENP; and 7) recreation and navigation. Initial focus was on flood control, drainage, and water supply.

Flood control made possible massive land-use changes that decreased the land available for water storage and recharge. These land-use changes and associated population growth resulted in a three-part ecosystem consisting of an urban component, an agricultural component, and part of the original natural system that is largely undeveloped but still impacted by man. These three components are interconnected by the flow of energy and resources (Browder et al. undated; McPherson et al. 1976; Odum et al. 1993). A comprehensive discussion of the natural and altered systems of South Florida was presented by McPherson et al. (1976).

A rapidly expanding human population approaching 6 million has developed in South Florida, mainly in upland areas such as the Atlantic Coastal Ridge but also in wetlands. The South Florida Ecosystem (i.e., the SFWMD area) encompasses all or portions of 16 counties. The combined population of the counties included in entirety (Broward, Collier, Dade, Glades, Hendry, Lee, Martin, Monroe, Palm Beach, and St. Lucie) was 4.9 million in 1990 and estimated at 5.1 million in 1993. The population of counties partially included (Charlotte, Highlands, Okeechobee, Orange, Osceola, and Polk) was 1.4 million in 1990 and estimated at 1.5 million in 1993 (Bur. Econ. Bus. Res. 1994). Although much of the population of some of these boundary counties resides outside the defined area, it still impacts South Florida. For instance, the city of Orlando is outside the boundary, but it lies just upstream of the head of the Kissimmee-Okeechobee-Everglades drainage. The large tourist area of Kissimmee-Walt Disney World is actually within the SFWMD boundary.

Most of the population of South Florida is concentrated along the Lower East Coast in Palm Beach, Broward, and Dade counties, the most heavily urbanized area in the state. With a combined population of 4.1 million people in 1990, these three counties are home to more than 30% of Florida residents. Dade County alone comprises almost 15% of the state's population. Dade, Broward, and Palm Beach counties are first, second, and third, respectively, in the state's population rankings. Collier County on the West Coast has been the fastest growing county in South Florida. Between 1970 and 1990, its population quadrupled from 38,000 to 152,000 (Bur. Econ. Bus. Res. 1994).

This expanding human presence, with all its needs and demands, has dramatically changed the South Florida Ecosystem. In addition to hydrologic alterations that have decreased the natural ability of the system to store water in wetlands, soils, and the aquifer, the expanding population has created an increased demand for water for both urban and agricultural uses. When wetlands are developed, demand for water is increased by new users while, at the same time, the supply of consistently available water is decreased by loss of places to temporarily store water. Other changes that have accompanied population growth and economic expansion are water quality and treatment problems, soil subsidence in the Everglades Agricultural Area, nutrient enrichment, pollution by contaminants, fragmentation of habitats and landscapes by urban development, loss of wetland areas and functions to development, altered fire regimes, declines in reef and estuarine resources, and invasion of parks and natural areas by many non-native plants and animals introduced into South Florida. By addressing these problems, restoration of the South Florida Ecosystem will support more sustainable economic opportunities while at the same time improve the sustainability of the natural ecosystem.

Quality of life in South Florida is strongly affected by the condition of its natural systems, which provide many benefits to agriculture and urban communities. These benefits include adequate supplies of clean water, clean air, aesthetically pleasing natural landscapes, natural controls on agricultural pests, and an interesting diversity of wildlife and fishery resources. If the natural systems are destroyed or reduced, their free services are diminished or lost (Browder et al. undated; McPherson et al. 1976).

Agriculture is a significant land use in South Florida. Major products include cattle, sugarcane, vegetables, citrus, tropical fruits, rice, sod, and ornamental plants. Much of the U.S. winter supply of vegetables such as tomatoes, green beans, peppers, and yellow squash is provided by South Florida agriculture. Some South Florida crops are not grown commercially anywhere else in the U.S. Recently, land conversion to citrus has increased substantially as a result of interregional movement of citrus farming from Central to Southwest Florida following several severe freezes in the mid-1980s.

The South Florida Ecosystem is nationally and internationally significant for its wildlife and fish. Tourism is a major industry in the Region, and much of the attraction is due to the remaining natural areas and their resources. Recreational fishing and diving are significant to the overall economy of South Florida, both directly and through their stimulation of tourism. For example, recreational activities and tourism account for 50% of the total employment in Monroe County, which consists of the Florida Keys and much of ENP. Recreational fishing contributes about $77 million to the economy per year, while diving contributes about $354 million to the Florida Keys alone. ENP (a designated World Heritage Site and Biosphere Reserve), BNP, and other scenic wetland areas are large tourist magnets, as are many State, county, and municipal lands maintained as parks and natural areas. The future of this segment of the tourism industry is directly tied to the condition of the South Florida Ecosystem. Clearly, ecosystem restoration means improvement in local quality of life and the regional economy.

A comprehensive discussion of the natural and altered systems of South Florida was presented by McPherson et al. (1976). The SSG (1993) described the defining characteristics of the South Florida Ecosystem and the problems that have resulted from hydrologic alterations and other anthropogenic changes. Nine geographic subregions were delineated, and restoration objectives were proposed for the Region as a whole and each of the subregions. For the present report, boundaries of the subregions were slightly modified and scientific information needs are presented for 10 subregions (Figure 1).

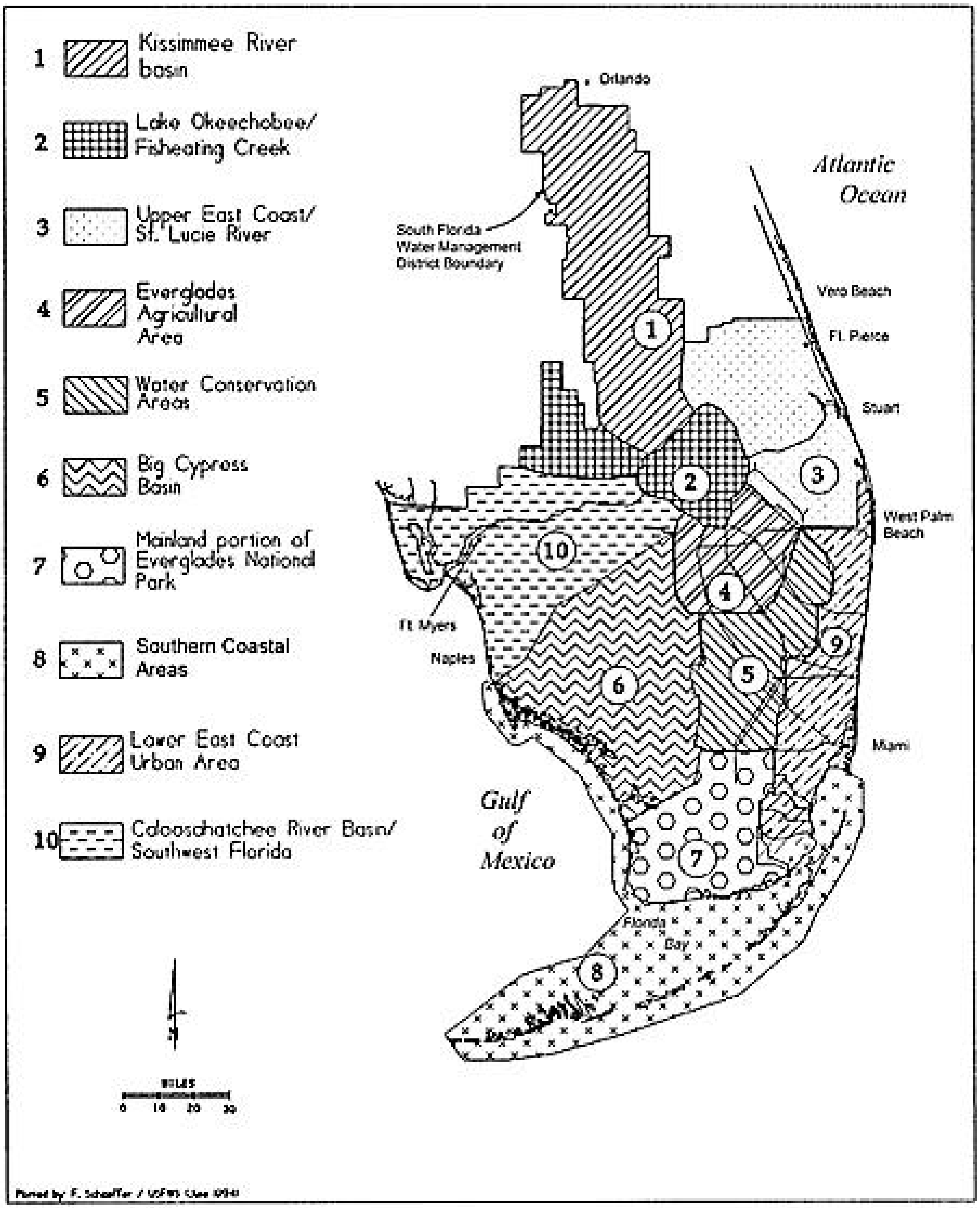

Figure 1. South Florida subregions

GOAL

The overall goal of the restoration effort is to restore a sustainable South Florida Ecosystem that preserves the valued properties of South Florida's natural systems and supports productive agriculture-, fishery-, and tourist-based economies and a high quality of urban life. Sustainability means high natural productivity, human and ecosystem health, and resiliency to climatic extremes and catastrophic events. It also means long-term accommodation of needs of human systems, such as flood control, irrigation, and drinking water supply.

The scientific approach to accomplish this goal is presented in the following chapter.

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SCIENTIFIC APPROACH

INTRODUCTION

This chapter addresses the entire South Florida Ecosystem, cutting across the artificial boundaries of the 10 subregions, as well as geopolitical and geomorphological boundaries, to present the broader issues of developing an interagency and interdisciplinary ecosystem-based science program to support South Florida Restoration. Here are presented the general premise and approach, with brief discussions on monitoring, modeling, and special restoration support studies. This chapter is not intended as a comprehensive synthesis or overview of subsequent chapters of this report. Rather, it deals with major cross-cutting issues, including management aspects of the science effort, and identifies critical gaps in coverage, which occur particularly at the boundaries between subregions and disciplines.

BACKGROUND

Water is life for South Florida's human and natural systems. Clean, abundant water was a fundamental characteristic of the original South Florida Ecosystem. The increased human population and human activity in South Florida have brought not only an increased need for water but also deterioration in water quality and a decrease in water supply. The latter was caused by loss of dynamic, or short-term, water storage capacity that accompanied drainage. Alterations in the hydrologic system are thought by many to be the root cause of dramatic declines in fish and wildlife populations and their habitat across the South Florida Ecosystem.

The basic premise of the restoration effort is that better water management will provide sustainability across both human and natural systems. Therefore, the working hypothesis of the adaptive management approach adopted by the Interagency Working Group is that hydrologic restoration is the prerequisite to ecosystem restoration. This is consistent with conclusions of a panel of independent scientists that hydrologic restoration may be the best option for achieving recovery of wetland-dependent endangered species (Orians et al. 1992). To resolve the hydrologic issues is the first concern. The highest priority science is that which determines how to modify the structure and operation of the hydrologic system to accomplish restoration. Some systems (e.g., uplands) may, however, require focus on additional restorative approaches.

The predrainage, or natural, hydrologic system supported the landscape patterns; clean and abundant water supplies; and large populations of wading birds, game fish, and other wildlife characteristic of the predrainage ecosystem. Therefore, the natural hydrologic system, as reconstructed with hydrologic models, can provide general guidelines on how to design an ecologically supportive hydrologic system for South Florida. The conversion of natural lands to urban and agricultural lands that has already taken place in South Florida precludes exact reinstatement of the natural hydrologic system everywhere. It is expected that reconstruction of key features of the natural hydrologic system on public lands, or as they influence public lands and waters, will result in changes in the ecosystem in the right direction -- toward a sustainable healthy state.

MAJOR ISSUES

***Note*:** Progress on several issues critical to South Florida restoration was stimulated by circulation of the draft of this report. Because of their importance, statement of all issues is retained in this final edition.

> Monitoring projects underway or planned by various agencies have not yet been coordinated or integrated into the South Florida Ecosystem Restoration effort. Major gaps in monitoring needs, considered regionally and in view of proposed ecological assessment indicators, are expected to be revealed by planned coordination and integration efforts.

> Past piecemeal attempts to solve environmental problems associated with the C&SF Project have led to the present seriously deteriorating state of the ecosystem. A holistic, region-wide ecosystem approach to monitoring, support studies, and modeling in a coordinated interagency and intergovernmental framework is the only means to attain restoration, but its achievement requires special effort and application of personnel and supporting resources.

> Hydrologic models currently existing or under development do not have the geographic coverage required to meet region-wide ecosystem management needs or to provide the hydrologic information for regional ecological models that are under development. With existing hydrologic models, the ecologic model cannot show whether a proposed water management strategy might increase feeding opportunities for wading birds in one part of the region without decreasing them to a greater extent somewhere else -- and then determine the consequences of these changes for resident wading bird populations. With existing hydrologic models, one cannot readily see what happens to water levels in Lake Okeechobee when the system is operated to restore near predrainage flows to Florida Bay.

> Existing hydrologic models do not extend to the coast and therefore cannot show how physical and ecological processes in the mangrove zone are affected by water management strategies. Furthermore, because they stop short of the coast due to lack of critical topographic data, existing hydrologic models cannot provide adequately detailed and realistic freshwater inflow data needed by the hydrodynamic models Congressionally mandated for Florida Bay to show how bay salinity and circulation patterns respond to freshwater inflow variations. Missing and requiring a major directed effort are hydrologic models with tidal and salinity components for the entire coastline of South and Southwest Florida. These models are needed to support regional ecological models of wading birds and fish and to provide input to hydrodynamic models of coastal waters.

> Restoration management using the adaptive management approach will be heavily dependent upon simulations from models, particularly hydrologic models. Yet the most suitable current hydrologic models cannot be used to test alternatives for the interagency restoration effort on a timely basis.

> Systems of nested models are needed, in which finer resolution can be provided to address some questions and coarser resolutions can be provided to address others.

> Modeling and special studies are most effective when complementary, but modeling is not well integrated with present scientific studies, and funds for modeling usually do not include sufficient funds for special supporting studies, including verifications.

> Use of models as technical tools in the restoration effort requires buy-in by all involved or interested parties. An objective process is needed to evaluate existing models within the context they are being used and ensure necessary improvements are made, while at the same time protecting useful models against attacks on their credibility. The fact that useful, credible models are available should not preclude development of new models that can address problems of resolution, scope, and flexibility.

> Certain key species (e.g., apple snail) or communities (e.g., periphyton) that might be suitable ecological indicators because of their important roles in the ecosystem or sensitivity to anthropogenic changes are so poorly studied they cannot be used as indicators. Furthermore, lack of knowledge about the response of these species or communities to hydrologic and nutrient variables may seriously handicap the restoration effort.

> Flexible and sustained resources are essential to an effective, comprehensive restoration effort. The various involved agencies have unique and complex funding strategies. There is no specific South Florida Ecosystem Restoration funding source. Thus, some critical activities needed at early stages in the restoration process are being neglected for lack of directed resources.

> Critical linkages between subregions are not being adequately addressed by agencies. Florida Bay is perceived as being in a crisis state, demanding immediate attention, and alteration in freshwater flow is thought to be a major contributor to its decline. Yet models that cover the critical mangrove zone between the Everglades and the bay are not yet under development, the topographic data required for the models are not yet being collected, and salinity data of the required spatial and temporal resolution to relate freshwater inflows to salinity and circulation patterns are not yet being obtained.

> Issues of agency authority are at times a barrier to focusing efforts at problem sources. Control of harmful nonindigenous plant species is an arena where there are jurisdictional gaps. The many aggressive upland species invading publicly owned natural areas are not included in major management and science initiatives, which appear confined primarily to control of aquatic weeds, melaleuca (*Melaleuca quinquenervia*), and agricultural pests. Soil subsidence is another arena where there may be jurisdictional gaps.

> Information exchange is a problem, because there is so much information in the hands of myriad sources, including local governments.

> Many people who live in South Florida do not realize the benefits they receive continuously from a functioning natural ecosystem and what ecosystem collapse would mean to them. Both tangible and intangible connections between natural and human systems need to be quantified and widely communicated while reinstatement of a sustainable system is still possible. Some obvious examples are decline of Florida Bay fisheries, elevated mercury concentrations in fish and alligators in the Everglades, and drinking water quality problems in South Florida water treatment plants.

> Potential opportunities need to be explored for configurations of land and water that lead to ecosystem restoration and enhanced quality of life and economic sustainability in human communities.

> Decision makers and the general public appear not to understand the consequences of development in wetlands. A scientifically based analysis is needed to demonstrate alternative futures under various land and water configurations.

> Agricultural applications of pesticides are enormous in South Florida, compared to other parts of the Nation, and the highly permeable nature of the South Florida substrate provides less protection against leakage into aquifers and aquatic environments than anywhere else in the U.S., yet there is no coordinated science program to support reduction in agricultural or urban pesticide usage.

> While monitoring for contaminants is extensive, little interpretation of monitoring results is occurring. Bioindicators are lacking for subtropical species and conditions (i.e., temperatures, high salinity, seasonal hypoxia, and concentration due to seasonal low rainfall coupled with high evaporation).

> An extensive program is developing to examine the effect of phosphorus loading on ecological balance in higher plant and algal communities; however, plant growth is affected by soil burdens of nutrients as well as nutrient concentrations in the water column. Dosing studies need to be augmented by gradient studies and process-oriented studies of nutrient cycling through soils, plants, algae, and the water column on different types of soils and under different types of hydrologic conditions.

OBJECTIVES

The goal of the Science Subgroup is to develop an interagency, interdisciplinary science program that will guide restoration actions by determining relationships between ecosystem function and hydrologic regime and describing hydrologic conditions required to support the characteristic landscapes, biodiversity, and wildlife abundance of predrainage South Florida. The major science objectives to accomplish this goal are shown in Figure 2. The science program will provide: 1) a scientific basis for management decisions (e.g., regulatory actions, land-use permitting), and 2) information that might lead to increased beneficial interactions between natural and human communities.

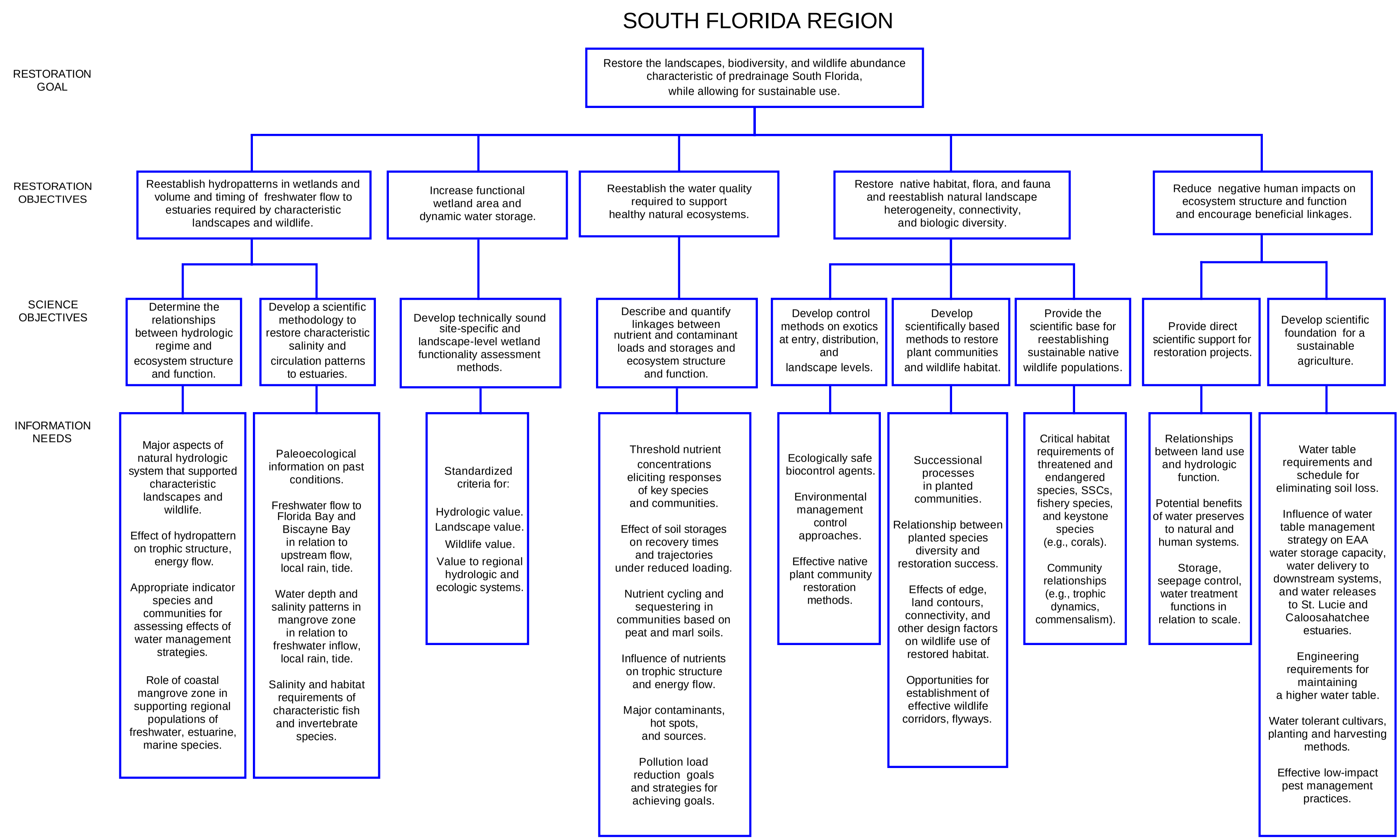

Figure 2. South Florida region-wide goal, objectives, and information needs

APPROACH

The scientific investigations identified in this report are directed at:

1. Characterizing the predrainage system and comparing it to the present system, particularly hydrologically.
2. Determining the key characteristics of the former natural hydrologic system that supported the rich diversity and abundance of wildlife that have been lost.
3. Designing structural and operational modifications of the C&SF Project that would recreate the key characteristics of the natural hydrologic system.
4. Assessing the hydrologic and ecological results of these modifications.
5. Modifying the design to make improvements.

Given this approach, adaptive management techniques are particularly appropriate. Following is a description of the adaptive management approach, as recommended for the South Florida Ecosystem Restoration effort.

Adaptive Management

Adaptive management is a structured, iterative approach for improving resource management. It accepts, *a priori*, the fact that information used in making resource management decisions is imperfect and, as decisions are implemented, a structure must be in place to gain better information and adjust the implemented action accordingly. This structure has three elements -- models, restoration support studies, and monitoring -- used as coordinated, supportive tools. Models (hydrologic, ecologic, etc.) provide a framework for restoration support studies that lead to development of better information. This information is used to propose alternative actions, which are then compared by means of models that simulate their consequences. Once an alternative is implemented, monitoring is used to test responses. Models help interpret monitoring data, and this information can be used to design better alternatives, as well as better models. All three elements are critical to successful restoration.

Periodic environmental assessment, utilizing modeling to predict outcomes and monitoring to test the predictions, is the operational foundation of the adaptive management approach. Adaptive management is a means of using the measured outcome of management actions to make corrections and adjustments in management actions that will improve the probability of achieving objectives. Preliminary modeling and follow-up monitoring are essential to the application of adaptive management, as is continuing substantive communication between scientists and managers.

Scale and resolution are major concerns in planning the related use of several models, and special attention should be given to addressing issues of scale and resolution early in the planning of restoration science. Scale and resolution in monitoring should be coordinated with model scales and resolution.

As applied in the South Florida Ecosystem Restoration effort, adaptive management does not necessarily mean large-scale experimentation but rather having a protocol in place to select among alternative actions and to gain useful information regarding ecosystem response to a restoration action, once it is taken. Implicit in selection of a management action is the hypothesis that the system will respond favorably to that action. Models help formulate this hypothesis. Monitoring is the means of testing the hypothesis. Models and monitoring are applied within the framework of an assessment protocol that identifies ecological indicators to be used in determining effects, defines how models will be applied at various stages of decision making, ensures models are designed to provide the output required for making evaluations, and focuses monitoring efforts.

Selection and use of appropriate ecological indicators is essential to success of the restoration effort. The indicators must be readily measurable and sensitive to the types of changes to be made. They should relate to restoring the characteristics of the natural system. Species and communities that play major roles in ecosystem function or reflect region-wide ecosystem function should be given priority. Several indicators should be selected, each with a different set of habitat requirements and representative of a larger group. Those species and communities for which information and time series of data already are available should be used initially as indicators.

The 1993 SSG report listed a number of restoration success criteria for evaluating progress of the restoration effort. Assessment indicators also have been presented by SFWMD (1993) and Hoffman (1994). Recently, the SSG revisited and updated its criteria as suggested restoration success indices. They were organized into two types: precursor success indices and ecological success indices. Precursor indices refer to conditions thought to be favorable to ecological restoration and are:

> Reinstatement throughout the system of natural hydropattern and sheetflow, as approximated by natural system models.
> Reduced body burdens of mercury in top carnivores.
> Reduced concentrations of known contaminants in canal surface sediments and the water column at SFWMD monitoring locations.
> Reduced rate of soil subsidence.
> Reduced phosphorus loading.
> Reinstatement of natural salinity patterns in estuaries.
> Reduced turbidity in estuaries.
> Increased ecotone/buffer area throughout the system.
> Increased spatial extent of wildlife corridors/greenways/flyways throughout the system.

Ecological indicators recommended by the SSG are:

> Reestablishment of predrainage wading bird nesting colony locations and timing of nesting.
> Improved recruitment of fishery and nonfishery species.
> Increases in fish abundances and reinstatement of species in pre-disturbance locations.
> Reduction in prevalence of deformed fish in estuaries.
> Increased diversity of native landscapes.
> Reappearance of missing vegetative landscapes.
> Reduction in expanses of nutrient-tolerant plant species.
> Reduction or elimination of invasive exotic plant species.
> Periphyton community taxonomic composition characteristic of oligotrophic, natural hydroperiod systems.
> Population increases in threatened and endangered species.
> Increased coral cover.

It would be a serious mistake to think restoration can succeed simply on the basis of modeling and monitoring. Field and laboratory studies that acquire critical information about the system must be a major part of development of scientific information to support restoration. Syntheses of available information, including historic information, in the context of present issues and questions is a necessary component of an effective science program.

Following are brief discussions of the monitoring, modeling, and support study needs of the restoration effort. Modeling is discussed in greater detail in a separate chapter. A chapter on mercury discusses modeling, monitoring, and support studies needed to address the mercury problem. Needs for restoration support studies and monitoring are covered in greater detail in chapters on nonindigenous species, protected species, and contaminants. Needs for restoration support studies and monitoring are the major focus of chapters on the 10 subregions.

Because planning of integrated scientific investigations is a dynamic process and more than a year has passed since the draft of this document was circulated, some information needs described in this report now are being addressed, indicating that the strategy of working together to synthesize needs, inventory planned activities, and communicate priorities and gaps is working. A strategic plan, updated annually, is needed to provide up-to-date information on critical needs and gaps. The precursor of such a plan, in addition to this Scientific Information Needs document, was a report produced for FY97 budget considerations (SSG 1995). It was used in financial planning for the integrated South Florida Ecosystem Restoration effort.

Monitoring

Long-term monitoring is essential to the adaptive management process. Only monitoring can systematically reveal the results of implemented management actions. Regular, systematic surveys of species, communities, and conditions pertaining to certain ecological indicators will allow managers to evaluate the degree to which restoration is meeting its stated goals and objectives. Advance monitoring will help document baseline conditions, including seasonal and year-to-year variation. Comparison of monitoring results to expectations will provide necessary insight for fine-tuning assessment models.

Development of a comprehensive system-wide monitoring plan should be guided by an assessment protocol and should be oriented toward obtaining time series information on ecological indicators. The monitoring plan should coordinate the many ongoing and planned monitoring programs of governmental and nongovernmental entities throughout South Florida. Coordination of these efforts can ensure consistency in terms of spatial and temporal resolution and parameters covered and will prevent gaps, particularly in relation to ecological indicators.

Geospatial data are particularly critical to the South Florida Ecosystem Restoration effort. An active, ongoing process to integrate geospatial information over the Region will help ensure availability of high quality geospatial data. As a first step at interagency integration and coordination, representatives from the SSG, FGDC, FDEP, and SFWMD have conducted several workshops to encourage coordination, sharing, and mutual archival of all geospatial information regarding the Kissimmee-Okeechobee-Everglades watershed (Haddad et al. 1995). The workshops are preliminary to establishing a joint Federal, State, and local geospatial data agreement that ensures formal quality assurance and quality control, metadata protocols, and electronic retrieval-archival capabilities for coordination and data sharing. The workshops have been useful in identifying gaps in geographic areas and types of information covered. They have highlighted opportunities for further coordination and resource sharing (e.g., NBS-GAP, NOAA C-CAP, FWS NWI, and FGFWFC Integrated Habitat Plan).

Modeling

Models are another critical component of the South Florida Ecosystem Restoration process. Modeling activities will involve design of new models or adaptation of existing models of the following types: models of physical processes (hydrologic, hydrodynamic, transport, and meteorological models); ecosystem models (landscape and ecological models); nutrient models; and models of the movements, chemical transformations, and bioaccumulation of contaminants such as mercury. These models must be integrated into an interactive modeling system.

Models are essential to the adaptive assessment process and must be used to help establish targets, select among alternatives, and interpret monitoring information to assess progress. Hydrologic models can reveal major characteristics of the South Florida hydrologic system prior to drainage and show how various proposed changes in water management may affect the hydrologic regime. Landscape and ecological models, linked to the output of hydrologic models, can help determine key features of the natural hydrologic system that were most important to sustaining a healthy ecosystem. Similarly, linked hydrologic, landscape, and ecological models can show -- given present population levels, organic soil deposits, sea level, and flood control and water supply requirements -- how characteristic natural landscapes and wildlife can most effectively be restored on public lands and in inland and coastal waters.

An integrated hydrologic modeling system covering the entire South Florida Ecosystem, developed from existing subregional models, is a major need. The output of hydrologic models is the required input to all other types of models. Hydrologic models can support model-based studies related to natural resource rehabilitation, as well as agricultural and urban sustainability. Fortunately, some hydrologic models that can be used in the restoration effort already exist, although replacements that can be more readily altered to simulate alternative management strategies are urgently needed.

The two most useful models to date are the South Florida Water Management Model (SFWMM) and its corollary, the Natural System Model (NSM). The SFWMM was developed by the District. The NSM, initially developed by the SFWMD and ENP, continues to be refined and improved by the SFWMD in conjunction with the SFWMM. These models will be the core of the proposed hydrologic modeling system until a new regional model, also being developed by the SFWMD, becomes available.

The "natural system" model is an important concept in the restoration effort. Natural system hydrologic models are models that have been calibrated for present-day conditions and then stripped of all canals and other control structures to approximate the predrainage hydrologic system (Walters et al. 1992; Fennema et al. 1994). The output of natural system hydrologic models provides an objective view of flow volumes, water movement, and surface water patterns in response to rainfall in the predrainage hydrologic system. Results of exploratory work with natural system models have provided invaluable insight on ways in which the hydrologic regime has been changed by the existing network of water control structures. The NSM is being used to help establish targets for hydrologic restoration. Because elevation changes have occurred in the Everglades due to subsidence of organic soils, predrainage topography has been reconstituted for the NSM to replace present topography and is being used in simulations beyond Fennema et al. (1994).

While hydrologic models are the first requirement of the restoration process, other models also are needed. Hydrodynamic models must be used to translate output of hydrologic models at the coastal edge into salinity, circulation, and mixing patterns in the estuaries. Special hydrologic-hydrodynamic models are needed to approximate water depth and salinity patterns in the mangrove zone, which is influenced by freshwater inflow, seasonal and long-term sea-level changes, and tide. Ecologic models are needed to translate hydropatterns in freshwater and mangrove areas into ecologically meaningful outputs (e.g., wading bird reproductive success) and to relate salinity and circulation patterns to secondary productivity and ecosystem health in the mangrove zone and estuaries.

Meteorologic models are needed to simulate rainfall and wind on dense spatial grids in areas where it is sparsely measured, such as the mangrove zone and Florida Bay. Meteorologic models can be linked to hydrologic models to help determine the effect that present and future water management strategies may have on rainfall patterns. Water quality models are needed to measure the effect of water management strategies on water quality in both freshwater wetlands and estuaries.

Model development currently underway at the SFWMD is vital to the restoration effort. In addition to hydrologic models, the SFWMD also is developing the Everglades Landscape Model that will be very useful. This model has the capability to allow vegetation changes, brought on by hydrologic changes, to further change the hydrologic regime. It also has the ability to follow soil accumulation and subsidence processes, as affected by hydrologic regime. The SFWMD is engaged in other modeling, monitoring, and process-oriented studies focused primarily on resolution of water quality problems, especially phosphorus. We propose integration of SFWMD activities with Federal efforts into a comprehensive South Florida Ecosystem Restoration Science Plan.

Empirical Restoration Support Studies

Empirical studies are the third essential element of the adaptive management approach. Science projects that should be given the highest priority in planning are those that address critical issue-related questions about the system, assist in designing hydrologic modifications to the system, and/or increase the reliability of the ecological assessment procedure. Species, communities, and approaches for empirical studies are discussed in the context of special topics or subregions in subsequent chapters.

Selection and use of appropriate ecological indicators is vital to the restoration effort. There is, therefore, a compelling need to learn more about native wildlife populations and vegetation communities, particularly their responses to hydrologic conditions, nutrient loading, catastrophic events, climate changes, and accumulation of contaminants such as mercury. Species and communities that play especially important roles in ecosystem function are appropriate subjects for ecological assessment indicators, especially if known to be sensitive to hydrologic alteration. Species should be selected that will represent groups of species with different habitat requirements. For instance, the wood stork and the snail kite would be complementary. Both are sensitive to hydrologic regime, but each has different requirements. The American alligator, which has another set of requirements, might be another complementary addition to this selected group. Indicators of region-wide ecosystem function would be particularly useful. The wood stork and other wading bird species, because their feeding ranges are large, integrate information on secondary productivity and hydropatterns across broad areas in their choice of colony sites and production of fledglings. Pink shrimp, because they are a major prey of many fish species, represent the overall productivity of the estuarine ecosystem with their recruitment to the Tortugas fishery.

Initially, ecological assessment measures should be based on those species and communities to which considerable scientific attention has been given in the past so that both time series of data and an intellectual basis for model design are available. Other key species or communities should be identified for new scientific investigations that will provide a basis for using them to measure restoration success. Apple snails, crayfish, prawns, and some of the aquatic herpetofauna are examples of ecologically important species about which little is known concerning their population biology and ecology. Forage fish and macroinvertebrates in both freshwater and coastal wetlands are seriously understudied, yet important in the transfer of energy through food webs. The apple snail, for instance, is the sole food of the endangered snail kite and also is an important food source for many other Everglades animals. The periphyton community makes up as much as half the biomass in parts of the Everglades and is thought to be an important food-web base. Although some information is available with which to develop an ecological indicator based on periphyton, this community is poorly studied, considering its complexity, its relative biomass, and the importance of microscopic algae as an energy and nutrient source for many aquatic organisms.

Studies should be conducted on species of special concern, particularly those listed as threatened or endangered under the Federal Endangered Species Act or by the State of Florida. The large number of endangered and threatened species in South Florida reflects loss of habitat and alteration of ecological processes. Better information about these species will make recovery of these populations as part of ecosystem restoration more likely. Science topics directed toward recovery of species are given in Table 1. Information needs for some protected species and species of special concern are presented in Table 2.

Field studies and field experiments, such as nutrient dosing studies and small-scale tests of the effect of altered hydropatterns or waterflow patterns, are needed to help separate the influence of causal factors. Paleoecological studies that lead to a better understanding of past conditions, effects of major aperiodic events, and past and future effects of ongoing processes such as sea-level rise also are critical to successful restoration.

Recurring but unpredictable events such as hurricanes, freezes, and fires will influence the success of ecosystem restoration, and their effects must be understood. Aftermaths of these events provide priceless opportunities to gain understanding of the system that would not otherwise be obtained, as studies following Hurricane Andrew are demonstrating.

Environmental conditions vary naturally in South Florida's wetlands due to seasonal rainfall and stochastic events such as hurricanes and fires. As human population pressures on wetland ecosystems increase, it is crucial to be able to distinguish effects of natural variation on aquatic communities from the effect of human interference. Surprisingly little is known about community structure and energy-flow pathways of South Florida's aquatic systems and their responses to changes in environmental conditions. Trophic pathways leading to secondary production that supports wading birds, alligators, and other major predators of this system are particularly poorly known. Exotic species are becoming significant components of these communities in some areas. Their roles in these communities and effects on native species are unknown.

Field and laboratory studies that are integrated with modeling efforts will enhance the information obtained from both approaches to scientific investigation. Models become more effective over time as relevant information concerning input and design modification is acquired. A list of special studies particularly needed in critical modeling work is given in Table 3. Several special studies are already taking place in conjunction with related modeling. The value of their results will be magnified by their use for designing, refining, or quantifying models.

Considering the compelling need to better understand the natural system before it was impacted by modern development, relatively little paleoecological work has been done in South Florida. Records of pollens, algal tests, and mollusk shells in soil cores can reveal past landscape patterns and concurrent environmental conditions. Results of such work could help augment efforts to visualize South Florida hydrologic and ecological systems prior to modern development, provide a historic perspective within which to view current ecological problems, and show how landscapes and species responded in the past to catastrophic events and climate and sea-level changes. Initial emphasis of paleoecological work should be on the central Everglades, the mangrove zone, and northern Florida Bay.

Table 1. Proposed special studies.

Recover Populations of Rare, Threatened, and Endangered Species:

- Identify species "on the brink" of listed species status.
- Determine ecological requirements for species recovery, especially considering interaction with other native flora and fauna (using GIS-based, integrated, multispecies approach).
- Assess status and trends of all threatened and endangered species and ongoing interactions with other native flora and fauna (using GIS-based, integrated, multispecies approach).

Restore Native Community Structure in Terrestrial, Freshwater and Marine/Estuarine Ecosystems:

- Assess status and trends of community structure in key assemblages such as coral, seagrass, wading birds, fish, and hardwood hammocks.
- Identify and understand major influences (i.e., nutrients, mercury, pesticides, habitat alteration, hydrologic alterations, and global change) on natural community structure and productivity.
- Determine role of point and nonpoint inputs of nutrients, mercury and pesticides in regulating community structure, and primary and secondary production patterns and trends in freshwater ecosystems.
- Determine role of natural and modified hydrology in regulating primary and secondary production patterns and trends.
- Assess effect of freshwater and nutrient inputs on community structure and productivity of marine and estuarine ecosystems.

Halt and Reverse Invasion of the South Florida Ecosystem by Exotic Fauna and Flora:

- Identify potential pathways for new introductions.
- Determine factors that influence susceptibility of faunal and flora communities to exotic invasion.
- Develop environmentally "safe" biologic controls for exotics.
- Identify non-native species that have potential to become problematic, especially due to restoration activities.
- Identify effects of invasive exotics on natural community and ecosystem biodiversity.

Table 2. Proposed studies on protected species and species of special concern.

	Population Dynamics	Habitat requirements	Trophic relations	Census
Birds				
Cape Sable seaside sparrow	X	X		
Wood stork	X	X	X	X
Snail kite	X	X	X	X
Bald eagle	X			X
Red-cockaded woodpecker	X	X	X	X
Coot				X
Limpkin				X
Anhinga				X
Mammals				
Florida panther		X	X	
Lower Keys marsh rabbit				X
West Indian manatee		X	X	X
Round-tailed muskrat				X
River otter				X
Reptiles				
Sea turtles		X		X
American crocodile	X			X
American alligator	X	X		X

Table 3. Studies that will help develop an information base for assessment indicators and models.

Wading Bird Studies

- Systematic Reconnaissance Flights
- Nest success studies
- Foraging habitats
- Colony census
- Parasite studies

Freshwater Fish Studies

- Expand current sampling
- Life history parameters (otolith)
- Food-web studies (gut content, isotope studies)
- Bioaccumulation (mercury)
- Genetics study
- Predator-prey studies (mesocosms)

Freshwater Invertebrate Studies

- Community composition
- Food webs (gut content, isotope studies)
- Biocontaminants
- Predator-prey studies (mesocosms)
- Autecology of key prey species of higher organisms, particularly apple snails,crayfish, and prawns
- Microinvertebrate communities associated with periphyton

Herpetofauna Studies

- Autecology of major wetland species, particularly snakes and frogs.

Mammal Studies

- Range expansion of feral pigs
- Census of declining species

Nonindigenous Animal Species Studies

- Non-native survey
- Life history
- Control studies
  (a) Invertebrates
  (b) Fish

Substrate Profile Studies

- Peat mass, peat accretion rates (marker horizons throughout Everglades)
- Paleoecological studies

Support Landscape Model Development

- Landscape/vegetation
- Gradient analysis
- Soil surveys
- Topographic surveys
- Succession models (macrophyte/periphyton)

Support Integration with Faunal Models

- Fish community-based
- Wading bird community, statistical habitat
- Snail kite (statistical habitat)
- Deer/panthers

Threshold Studies

- Mass balance models
- Internal cycling and transport models
- Carbon flux models-foodweb
- Phosphorus loading measures (monitoring)
- Pesticides (sources, transport, fate)

Monitoring

- SWIM and EFA required monitoring
- Restoration assessment monitoring (success measures)

Florida Bay Studies

- Photointerpretation to map bottom habitat
- Bottom topography
- Sedimentary record (disturbance frequency and change in deposits)
- GPS surveys (tide gauges)
- Salinity mapping under various conditions of freshwater inflow
- Hydrodynamic modeling
- Ecological studies relating marine resources to salinity and other environmental variables

Opportunities should be sought for medium-scale experiments to determine how landscapes and wildlife respond to manipulation of water regime and nutrient loads. The Frog Pond, Hole-in-the-Donut, Holey Land, and Rotenberger Tract are possible experimental sites in which hypotheses on how to restore characteristic natural landscapes could be tested. Every implemented modification of the C&SF Project that is expected to improve ecological conditions should be treated as an experiment that tests the hypothesis that ecological conditions will improve in certain ways.

The existing literature, including early studies, should be reexamined for clues about the predrainage system, the influence of catastrophic events, geologic processes, and the relationship of landscape patterns to functionality. The restoration effort provides today's scientists with new perspective for reviewing and synthesizing previous work.

Evolving Mutually Supportive Human and Natural Ecosystems

To accomplish the goals of the South Florida Restoration effort, it is necessary to: 1) recreate for South Florida's remaining natural areas the overall hydrologic support functions that, prior to drainage, were provided by lands now occupied by urban and agricultural development; and 2) improve quality of life for human populations.

Issues of land use, routing of stormwater runoff, and disposition of treated wastewater all relate to concerns for human water supply as well as protection of natural areas. Loads of nutrients, various contaminants, and total organic carbons associated with human alterations of the system relate to water quality. Several scientific investigations recommended in this report address these problems. Water quality is affected by land use and practices of individuals and industries. Finding a harmonious balance between South Florida's human populations and the natural ecosystem requires resolution of major issues concerning release of nutrients and contaminants into surface and ground waters. These issues and relevant scientific information needs are discussed in several subregion chapters.

The Everglades Settlement Agreement, Everglades Forever Act, and Clean Water Act mandate that threshold concentrations be determined for effects of phosphorus on the ecological balance of native flora and fauna. Dosing studies can show the concentrations of phosphorus that invoke changes in wetland communities. Other studies can show how best to reduce input of nutrients at the source and by passage through wetland water treatment areas. In addition to dosing studies and field studies already underway in the EAA and STAs, process-oriented and gradient analysis studies need to be conducted to determine how nutrient burdens in soils affect plant community composition and how best to restore native vegetation natural to a site.

Contaminants are another serious water quality concern in South Florida. Mercury has gained notice because of the human health hazard associated with its observed bioaccumulation in fish and higher organisms. Other contaminants also pose serious problems in South Florida. Biscayne Bay was in the top 10 of a ranking of estuarine drainage areas based on the potential of inventoried pesticides to impact estuarine organisms (Pait et al. 1992). The 1991-1992 Green Index (Hall and Kerr 1991) ranked Florida the worst state according to a composite water pollution index.

Pesticides and polycyclic aromatic hydrocarbons are present in the South Florida Ecosystem. Some pesticides (e.g., endosulfan) and PAHs (4- and 5-ring aromatics) are acutely and chronically toxic compounds. Because many are estrogen hormone mimics, possible chronic effects of these compounds include disruption of reproduction in wildlife and aquatic organisms. Endosulfan has a high bioconcentration potential and it or its breakdown products may accumulate in food chains. Furthermore, it has estrogenic properties that could potentially cause alteration of sexual development in both wildlife and humans. Atrazine, an herbicide heavily utilized in South Florida to control agricultural weeds, is another compound with estrogenic effects. Nemacur (active ingredient fenamiphos), widely applied to golf courses, causes fish kills when flushed to nearby waters after heavy rains, and leaching of Nemacur to groundwaters is also a serious concern (Zaneski 1994). Organic contaminants are the topic of a separate chapter in this report.

Water quality can be affected by water management. Trihalomethanes, which have been associated with human cancer and genetic defects, form in water treatment plants by an interaction of chlorine with dissolved organic matter found in raw water supplies. Water management affects the DOC in the raw water. The Biscayne Aquifer, which supplies most of the drinking water for Southeast Florida, is recharged not only by rainfall but also by canal flow from Lake Okeechobee and the Everglades. Natural Everglades waters were very clear, indicating a low content of DOC; however the DOC level is very high in South Florida canals. DOC is released into South Florida's waters by oxidation of drained organic soils and proliferation of algae and aquatic weeds in canals. Although technological methods are used by South Florida water treatment plants in order to reduce contamination of drinking water with chlorine byproducts, these solutions all have their problems and the best solution is very expensive. A water management approach to reducing trihalomethane formation should be explored in association with the South Florida Restoration effort.

Land use affects water supply as well as water quality. South Florida's water shortage problems are not so much an allocation problem as a problem of where to store the abundant wet season rainfall so it can be used during the dry season. Land-use decisions ultimately affect the amount of water that will be stored on land and in surficial aquifers. As more and more land is developed, it becomes more important for decision makers to recognize the influence of land use on water supplies and the ability to manage water both to restore natural systems and to serve urban and agricultural systems. Several proposed scientific investigations for the Lower East Coast Urban Area deal with quantifying and demonstrating the relationships between land use and water management.

Wetland regulatory programs and planning programs require technically sound methods for evaluating wetland functionality. This information is required for informed permitting decisions that take into consideration functions that a particular wetland area provides, including its role and contribution to the greater ecosystem. Wetland assessment approaches must be developed at two scales: landscape and site-specific.

South Florida has productive agricultural systems that could contribute to -- and benefit from -- ecosystem restoration. The EAA now contains a productive agriculture of major economic importance to the Region. However, this agriculture is on organic soils that are losing depth, primarily due to microbial oxidation resulting from drainage. The continued loss of soil is a severe agricultural concern that limits the lifetime of agriculture in the area. Release of phosphorus and dissolved organic carbons into drainage waters are environmental concerns associated with soil subsidence. Previous studies suggest that a zero-subsidence agriculture producing present crops and maintaining current harvest levels may be possible. A science program is proposed with the objective of developing the technology for this zero-subsidence system. It is possible that successful investigations would help modify the hydrologic function of the EAA, with respect to downstream natural ecosystems, to more closely resemble its predrainage function (i.e., providing dynamic storage and allowing conveyance of water from Lake Okeechobee). Management of water for zero subsidence and for improved quantity, timing, and location of flow to downstream natural systems might be compatible if control of subsidence can be accomplished by delaying release of wet season rainfall. A science program to halt subsidence while maintaining a profitable agriculture is described in the Subregion 4 chapter.

Many Federal, State, and local agencies operate in South Florida and, through regulation, taxation, insurance, subsidies, or other means, influence the course of events in not only deliberate but also inadvertent ways. Coordination of government efforts should involve identifying pertinent agency programs and policies and evaluating their influences. This should lead to recommendations that would improve consistency of government programs with the overall effort to restore the South Florida Ecosystem.

INFORMATION NEEDS

Critical scientific information needs identified for the South Florida Ecosystem as a whole are shown in Figure 2 in relation to the overall restoration goal and to specific scientific and restoration objectives. These needs are detailed in other chapters in this document on individual subregions or special topics. The following set of recommendations focuses on the process of scientific information development to fulfill the information needs in Figure 2 and highlights a few critical information gaps.

> **Develop an assessment protocol that helps focus modeling and monitoring activities on predicting and measuring restoration success indicators. Identify core modeling and monitoring needs. (Lead--SSG)**

An assessment protocol is needed to help focus monitoring efforts and define how models will be applied at various stages of the restoration effort. The assessment protocol must be developed concurrently with model development and preparation of a monitoring plan. Modelers and those involved in developing the monitoring plan should take part in preparing this protocol.

> **Establish a set of ecological indicators, starting with the assessment criteria recommended by SSG (1993). (Lead--SSG)**

Refine the original list of assessment criteria into a set of practical and sensitive indicators and develop them into an effective assessment tool. Coordinate selection of indicators with ongoing modeling and monitoring activities.

> **Propose potential ecological indicators for which little information is available and target these species or communities for special scientific investigations.**

Several key species and communities in the environment would be appropriate ecological indicators, except that little is known about them. For instance, the apple snail is the critical prey of several species, including the endangered snail kite, yet little is known about its population biology and ecology.

> **Establish groups to model the hydrologic, hydrodynamic, landscape, meteorologic, and ecologic processes of the South Florida Restoration area and develop an integrated region-wide modeling system. (Lead--SSG)**

Upgrade existing grid-based hydrologic models (SFWMM and NSM) and develop new ones to cover areas presently lacking coverage, including, particularly, the mangrove zone. Design a new generation of hydrologic models that can be more easily used to test alternatives. Develop a hydrodynamic model for Florida Bay to predict circulation, mixing, and salinity patterns in Florida Bay as a function of freshwater inflow and other variable factors. Support the hydrodynamic model with a regional numerical ocean circulation modeling system that can provide boundary conditions for the Florida Bay model. Develop ecological models that will translate hydrologic information into effects on the ecosystem.

> **Initiate ecological model development at the beginning of the restoration effort and integrate it with development of hydrologic and hydrodynamic models.**

Ecological models, even with cursory data, can identify the type of information that must be obtained from hydrologic and hydrodynamic models and illustrate why this information is needed. By developing ecological models concurrently with the hydrologic and hydrodynamic models to support them, scientists can ensure hydrologic and hydrodynamic models will provide suitable support for addressing ecological questions.

> **Fund modeling projects sufficiently to allow these projects to finance related special studies involving field and/or laboratory work.**

The best results are achieved if modeling is initiated at the beginning of the project rather than delayed until more information is obtained, and if special studies to obtain the necessary information are funded through the modeling group.

> **Integrate modeling with monitoring and science planning and use models to help organize information, communicate concepts and ideas, design studies, and identify critical information needs.**

Initiate modeling at the beginning of scientific studies rather than at the end to help ensure the studies are complementary and gaps in information are minimized. Models should be an essential component of investigations that include field studies, experiments, laboratory analyses, and other means of obtaining information. Models can be used to integrate results from several studies into a higher order of information.

> **Ensure the continued development and upgrading of natural system models as part of the hydrologic modeling effort in order to provide input data for ecological models.**

Comparison of the present system with the predrainage system is important to developing restoration targets. The best guide for understanding the ecological ramifications of changes in spatial extent and hydrologic conditions that have occurred is the simulated output of spatially explicit "natural system" hydrologic models supporting a system of ecological simulation models that operate at several scales.

> **Acquire critical freshwater inflow and salinity information required to develop and calibrate a hydrodynamic model for Florida Bay.**

A hydrodynamic model for Florida Bay will help determine the relationship between freshwater inflows and patterns of circulation and salinity. Freshwater inflow and salinity are major data requirements for hydrodynamic models. Current SFWMM and NSM models do not extend the full distance to Florida Bay and do not have the resolution and data to provide reliable flow estimates to Florida Bay. Spatial extension of these models or development of separate, connecting models of the mangrove zone (as suggested below) is a critical first step to understanding relationships between freshwater flow and bay salinity and circulation patterns. A high degree of resolution in salinity data is necessary to develop and calibrate hydrodynamic models. Augmentations and improvements in salinity monitoring programs are needed to support hydrodynamic modeling.

> **Acquire needed topographic data and develop models to simulate freshwater inflow, water depths, and salinity patterns within the mangrove zone and freshwater inflow to Florida Bay, Biscayne Bay, and the Gulf of Mexico.**

Physical models of the mangrove zone are a critical missing element in the overall restoration modeling effort. They are needed not only to connect existing water management models to estuaries, but also to simulate water depths and salinities in the mangrove zone so the effect of proposed water management strategies on ecological processes, such as reproductive success of wading birds, can be modeled.

> **Develop a monitoring plan, bringing together in workshop settings the major participants in present and proposed monitoring efforts. (Lead--SSG)**

Conduct special monitoring-related topic workshops, such as the Spatial Information Workshop of September 1994, to: 1) consider restoration assessment needs from monitoring, 2) explore current capabilities, 3) discuss existing monitoring activities and monitoring plans, 4) adopt common quality control procedures, 5) coordinate efforts, and 6) share resources and information. Prepare a comprehensive, integrated monitoring plan from results of these workshops.

> **Review and synthesize the historic and recent literature in the context of major issues and questions in the restoration effort.**

> **Develop the information base for application of the adaptive management approach, emphasizing determination of important relationships and building assessment capability. (Lead--SSG)**

Conduct special studies integrated with modeling and monitoring and acquire information that can be used in assessment to support the adaptive management strategy. Strengthen the scientific understanding that will enable effective management actions to be proposed and implemented (e.g., determine how vegetation communities and wildlife are affected by hydrologic regime, anthropogenic nutrients, and contaminants). Focus especially on species and communities that are proposed ecological indicators. Utilize the workshop approach, bringing together appropriate parties, including modeling and monitoring participants, as well as the management community.

> Develop scientific information and tools to support a multispecies ecosystem approach to the protection of endangered and threatened species.

Use GIS, remote sensing, food-web analyses, modeling, and other techniques to characterize critical habitat and environmental requirements for protected species.

> Conduct mesocosm studies to establish response thresholds for phosphorus concentrations. Expand nutrient studies to include soils.

Examine ecological balance in native flora and fauna in relation to phosphorus concentrations in inflowing waters and soils.

> Identify critical gaps in the pathways toward development of the scientific information and tools needed for ecosystem restoration. (Lead--SSG)

Sometimes progress in preparing information and tools is inadvertently delayed by lack of support for a critical link in the overall process. Such delays can be prevented by showing connections between projects required along important pathways.

> Develop and apply methods to relate socioeconomic conditions and human actions to ecosystem health in South Florida.

Human and natural ecosystems are mutually dependent, but these dependencies are not always recognized by decision makers. Science-based information specific to South Florida is needed to demonstrate the interdependency and point out opportunities to improve overall sustainability within the context of restoring the ecosystem.

> Develop scientific studies that will lead to productive, supportive interactions between natural and human systems.

In general, studies must address these questions: What are the critical feedbacks of the natural system to urban and agricultural systems and vice versa? How will the natural system and its support functions for humans be affected by different population levels and land-use configurations? What landscape combination will allow healthy natural systems and urban and agricultural systems to coexist?

> Conduct "consistency" analyses to determine present or potential influences of government activities (e.g., laws, programs, policies) on efforts to restore the South Florida Ecosystem.

Identify those programs and laws of government agencies that, through regulations, grants, tax incentives, or otherwise, may undermine the intergovernmental, science-based effort to restore the South Florida Ecosystem and those that can potentially enhance the ecosystem restoration effort. Give particular emphasis to factors that influence encroachment of urban or agricultural development into remaining wetlands and remaining upland natural areas.

> Develop technically sound *landscape-level* wetland functionality assessment methods that can be used by wetland regulatory and planning programs to make appropriate decisions.

The landscape-level wetland assessment method must be developed and implemented for all wetlands within the SFWMD boundary during development of the South Florida Comprehensive Wetlands Conservation, Mitigation, and Permitting Strategy. The methods should be capable of evaluating wetland areas into general high/medium/low functional categories. Landscape ecology concepts and GIS approaches should be employed. The methods should facilitate evaluating a particular wetland and its functionality in the context of the greater ecosystem and should be user friendly.

> **Develop *site-specific* wetland functional assessment methods that can be used by regulatory and planning programs as a basis for making appropriate decisions.**

Several different approaches currently are used for assessing development impacts and determining mitigation requirements, such as analyses based on ratios, relative scoring values, and integrated matrices. Consequently, there is no continuity of assessment techniques among projects, and it is difficult to compare results. The needed method should facilitate evaluating a particular wetland and its functionality in the context of the greater ecosystem, should be relatively easy and rapid to employ by professionals in the geographic area of application, and must produce consistent assessments of wetland impacts as well as uniform determinations of mitigation requirements. The method must also be realistic in terms of the volume of data required for specific wetland areas and take into consideration whether the assessment is done during the wet season or during the dry season.

> **Provide continuous support as an integral part of restoration operations budgets for this multiyear adaptive management effort. (Lead--SFERTF)**

Adaptive management for ecosystem restoration requires continual predictions and feedback from the interactive modeling, monitoring, and special study efforts -- and thus, continuous support.

> **Ensure resources to support planning, coordination, and oversight activities of the SSG. (Lead--SFERTF)**

A special annually replenished fund should be made available for SSG activities relating to planning, coordination, peer review, and other oversight activities needed to expand and strengthen the scientific basis for ecosystem restoration to ensure participation by all critical parties, Federal and non-Federal (including academic scientists).

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