SOUTH FLORIDA ECOSYSTEM RESTORATION:

SCIENTIFIC INFORMATION NEEDS

Science Subgroup

September 27, 1994

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DRAFT

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This report should be cited as:

Science Sub-Group. 1994. South Florida ecosystem restoration: scientific information needs. Draft, September 27, 1994. Management and Coordination Working Group, Interagency Task Force on the South Florida Ecosystem.

PREFACE

The Interagency Task Force in its September 23, 1993, Agreement concerning the South Florida Ecosystem Restoration, observed that the restoration effort needs to be founded on scientific information and mandated that it take an ecosystem approach. This document is structured to provide information in support of the ecosystem approach. It is the first step in the development of an ecosystem-based South Florida Comprehensive Science Plan that includes monitoring and modeling.

To aid the reader so that all are starting from the same perspective, some definitions are provided. An **ecosystem** is the entire dynamic complex of interrelating plants, animals, and microorganisms at a location and their environment. The ecosystem includes humans and their influences, when present. **Ecosystem management** recognizes and attempts to conserve the structure of natural ecosystems as embodied in species composition and food webs and major functions of ecosystems such as primary productivity and mineral cycling. It addresses the need to sustain viable populations of multiple species over the long term. Ecosystem management extends beyond management of natural communities to address the balancing of human needs with resource protection.

Grumbine (1994) lists the following mandates of ecosystem management:

- Maintain viable populations of all native species in situ.
- Represent within protected areas all native ecosystem types across their natural range of variation.
- Maintain evolutionary and ecological processes (i.e., disturbance regimes, hydrologic processes, nutrient cycles, etc.).
- Manage over long enough periods of time to maintain the evolutionary potential of species and ecosystems.
- Accommodate human use and occupancy within these constraints.

Grumbine (1994) refers to several dominant themes of ecosystem management. His discussion, slightly rephrased, follows below:

> Ecosystem management mandates examining a problem at more than one hierarchial scale (genes, species, populations, ecosystems, landscapes) and seeking connections between all levels. A major tenet of ecosystem management is conservation of ecological integrity. Ecological integrity is conserved by protecting native diversity and the ecological patterns and processes that maintain diversity. This is done by maintaining viable populations of native species, allowing natural disturbance regimes, reintroducing native extirpated species, and preserving ecosystems across natural ranges of variation.
>
> Ecosystem management requires more research and data collection (i.e., habitat inventory classification, disturbance regime dynamics, baseline species and population assessment, as well as better management and use of existing information). Managers must track the results of their actions so that success or failure can be evaluated quantitatively. Monitoring creates an ongoing feedback loop of useful information.
>
> Adaptive management is part of the ecosystem approach. It assumes that scientific knowledge is provisional and focuses on management as a learning process for continuous experiment in which incorporating the results of previous actions allows managers to remain flexible and adapt to uncertainty.

Humans are part of the ecosystem and cannot be separated from it in ecosystem management. Humans exert fundamental influences on ecological patterns and processes and are in turn affected by them. Human values play a dominant role in ecosystem management goals.

Management requires working across administrative political boundaries to address issues within ecological boundaries. Using ecological boundaries requires cooperation between federal, state, and local management agencies, as well as private parties. Managers must learn to work together and integrate conflicting legal mandates and management goals. Implementing ecosystem management requires changes in the structure of land management agencies and the way they operate. These may range from the simple (forming an interagency committee) to the complex (changing professional norms, alternating power relationships).

The next step in the process of developing a South Florida Comprehensive Science Plan is to circulate this report on information needs to support the restoration for further scientific input and comment by science peers, managers, and the public, who we hope will supply any missing pertinent information. This input will identify gaps and help set priorities. It then will become the basis for developing a science plan to supply the information needs for ecosystem restoration. The framework of this plan will be strategic questions that relate to restoration objectives and an assessment protocol that integrates modeling, monitoring, and special studies. This document was developed by many different authors. The urgency of its production in draft form at this time precluded attaining complete editorial consistency, and it is hoped that the reader will be patient with the variation in format and font among sections.

REFERENCES

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8:27-38.

Interagency Task Force. September 23, 1993. Interagency agreement on South Florida Ecosystem Restoration.

ACKNOWLEDGMENTS

Many scientists and resource managers throughout South Florida provided information for this report and participated in workshops leading up to its publication. Some of these persons reviewed and commented on earlier drafts of various sections. We wish to thank all who contributed information and helpful suggestions.

EXECUTIVE SUMMARY

This statement of scientific information needs is a beginning toward developing an organizing framework for collecting the information required for the ecosystem approach mandated by the Interagency Task Force in its September 23, 1993, agreement concerning the South Florida Ecosystem Restoration effort. The document is multiauthored and multidisciplined and has already been reviewed by many experts. Monitoring is to be a major component of the Science Plan. The Science Sub-Group decided that organizing the information needs to support region-wide restoration into a document that could be reviewed and circulated was a necessary preamble to the development of a coordinated, comprehensive monitoring plan. This is yet to come, although this draft contains many elements of monitoring.

This statement of scientific information needs is a precursor to a Science Plan to develop the knowledge to support planning and implementation of restoration strategies and the tools for incorporating the knowledge into the decision making process. The modeling, monitoring, and special studies called for in this plan will provide the information basis for ecosystem management.

The report that follows is subdivided into sections that detail the research needs of each of the subregions identified in the Science Sub-Group Report, as modified to include a Subregion 10. Subsections also were developed for the following special topics: mercury, endangered species, exotic species, and modeling (hydrologic, hydrodynamic, meteorologic, and ecologic). These are preceded by 1) a description of South Florida that addresses issues of sustainability and 2) a description of the approach to obtaining the scientific basis for restoration, as well as the issues involved in applying this approach.

Development of many of the sections involved bringing teams of experts together and gaining consensus regarding information needs. Other sections were developed through interviews with knowledgeable experts on the area or the topic. Since Subregions 3, 9, and 10 involved lands and waters controlled by local governments, local government representatives contributed substantially to the development of these sections. Background or initial organizing issues were those provided by the Science Sub-Group Report.

The subregion sections are uneven in format and detail, although all started with the same basic format: a) Major Issues, b) Background, c) Scope, d) Objectives, and e) Approach. Each group worked independently, and the format was more applicable to some topics than others. Therefore, the outline was modified to accommodate the separate needs. Science Plans were already in place for Sub-regions 1 and 8 at the time the Interagency Task Force Science Plan Draft was prepared. These two sections of this plan simply expand upon or integrate the existing plans into the region-wide restoration initiative. Discussion of Sub-regions 6 and 7 are combined because of similar research needs and restoration goals. Discussion of Indian lands (Seminole and Miccosukee Tribes) is included in the section on Sub-regions 6 and 7 since all of the Seminole Big Cypress Reservation and one-third of the Miccosukee Reservation are contained in the Big Cypress Basin.

THE REGIONAL ECOSYSTEM

The South Florida Ecosystem encompasses an area of approximately 28,000 km^2 comprising at least 11 major physiographic provinces, including 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, arranged along a topographic gradient of 2.8 centimeters per kilometer, with elevations ranging from about 6 m at Lake Okeechobee to below sea level at Florida Bay.

South Florida is a heterogeneous system of wetlands, uplands, coastal areas, and marine areas, dominated by the watersheds of the Kissimmee River, Lake Okeechobee, and the Everglades. Prior to drainage, wetlands dominated the ecosystem, covering most of central and southern Florida.

The wildlife abundance of predrainage South Florida was maintained by the complex annual and long-term hydrologic patterns of the natural system, as expressed in wet-dry cycles, drying and flooding rates, 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. Wetland productivity was dependent on dynamic storage and sheetflow, large spatial scale, and habitat heterogeneity. Native Americans, with an historical presence in South Florida of at least 10,000 years, are part of the natural ecosystem.

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, and location of freshwater flow to estuaries have been greatly modified. Excess nutrients and contaminants add to the problems experienced by living organisms in both the wetlands and estuaries. The pace of deterioration seems to be increasing. Known wildlife populations are now a fraction of their size of even 30 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.

The regional human population currently exceeds 5 million and is expanding rapidly. Tourism is a major industry, much of the area's attraction being due to remaining natural areas and their living resources. Agriculture, consisting primarily of sugarcane, winter vegetables, and citrus, forms another significant industry, which also is growing. Most of the population of South Florida is concentrated along the Lower East Coast in Palm Beach, Broward, and Dade counties. This is the most heavily urbanized area of not only South Florida, but the entire state. The west coast, on the other hand, is the fastest growing urban area.

This expanding human presence has dramatically changed the South Florida Ecosystem. In addition to hydrologic alterations, 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 freshwater 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. By addressing these problems, the restoration of the South Florida Ecosystem will provide for more sustainable economic opportunities while at the same time improving the sustainability of natural ecosystems.

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SYSTEM-WIDE SCIENTIFIC APPROACH

INTRODUCTION

The South Florida Ecosystem encompasses an area of approximately 28,000 km^2 comprising at least 11 major physiographic provinces, including 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. South Florida is a heterogeneous system of wetlands, uplands, coastal areas, and marine areas, dominated by the watersheds of the Kissimmee River, Lake Okeechobee, and the Everglades.

Prior to drainage, wetlands dominated the ecosystem, covering most of central and southern Florida. The 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 did not flood 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. All these habitats were interconnected on an extremely low topographic gradient (2.8 cm/km) with elevations ranging from about 6 m at Lake Okeechobee to below sea level at Florida Bay.

The large numbers of diverse biota that 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, drying and flooding rates, 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 sheet flow.** 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. Population resiliency was undoubtedly proportional to the extent of these wetlands because habitat diversity, the amount of seasonal refugia, and the 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. 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. The mosaic of habitat types and water depths provided the spatial framework for the production and survival of animals under a wide seasonal and annual range of hydrologic conditions. To some extent, maps of the 1980s, when compared with maps from the 1800s, reveal large-scale persistence of landscape patterns, even in the face of major anthropogenic disturbance.

Water quality and water quantity problems for the natural systems of South Florida, including the Everglades and the region's 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 the creation and implementation of the Central and Southern Florida Project in 1948. The enabling legislation gave the U.S. Army Corps of Engineers the 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 South Florida Water Management District (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 Everglades National Park, 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, which incorporates an urban component, an agricultural component, and a component 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).

South Florida is the home of 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 Water Conservation Area 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 and resources and use rights.

A rapidly expanding human population exceeding 5 million has developed in South Florida, mainly in upland areas such as the Atlantic Coastal Ridge but also in wetlands. The area considered in the South Florida restoration plan encompasses all or portions of 16 counties, corresponding to the boundaries of the South Florida Water Management District (SFWMD). 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. Another 1.4 million live in the counties partially included (Charlotte, Highlands, Okeechobee, Orange, Osceola,

and Polk) (Bureau of Economic and Business Research 1993). 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 boundary.

Most of the population of South Florida is concentrated along the Lower East Coast in Palm Beach, Broward, and Dade counties. This is the most heavily urbanized area of not only South Florida, but the entire state. With a combined population of 4.1 million people in 1990, these three counties are home to more than 30% of the residents of the state of Florida. Dade, Broward, and Palm Beach counties are 1, 2, and 3 respectively in the state's population rankings. Dade County itself comprises almost 15% of the state's population. 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 (Bureau of Economic and Business Research 1993).

This expanding human presence, with all its needs and demands, has dramatically changed the South Florida Ecosystem. In addition to hydrologic alterations, the changes include an increasing water demand by agricultural and urban uses, although 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 freshwater 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; the introduction of non-native plants and animals, some species of which have invaded remaining open lands, including parks and preserved natural areas; fragmentation of habitats and landscapes by urban development; loss of wetland areas and functions to development; altered fire regimes; and declines in reef and estuarine resources. By addressing these problems, the restoration of the South Florida Ecosystem will provide for more sustainable economic opportunities while at the same time improving the sustainability of natural ecosystems.

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, and an interesting diversity of wildlife and fishery resources. If the natural systems are destroyed or reduced, the free services they contributed are then attainable only at much higher cost, if at all (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. Many of the 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. Much of the U.S. winter supply of vegetables such as tomatoes, green beans, peppers, and yellow squash is sustained by South Florida agriculture.

The South Florida Ecosystem is of national and international significance for its support of wildlife and fish. Tourism is a major industry in South Florida, 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 mainly of the Florida Keys. Recreational fishing contributes about $77 million to the economy, while diving contributes about $354 million to the Florida Keys alone. Everglades National Park, Biscayne National Park, and other wetland scenic 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 Science Sub-Group (1993) described the defining characteristics of the South Florida

Ecosystem and the problems that resulted from hydrologic alterations and other anthropogenic changes. Restoration objectives were proposed for each sub-region (Fig. 1) and the region as a whole.

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 accommodation of needs of human systems--flood control, irrigation, and drinking water supply.

SCOPE

This section addresses the entire ecosystem, cutting across the artificial boundaries of designated 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 we discuss the general premise and the general approach, with brief discussions on monitoring, modeling, and special studies. The latter two topics are covered in greater detail in other sections.

MAJOR ISSUES

- Several monitoring programs are underway or planned by various agencies. These 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.

- The piecemeal approach to solving environmental problems that has been associated with the Central and Southern Florida Project has led to the present seriously deteriorating state of the ecosystem. A holistic, region-wide ecosystem approach to research, monitoring, and modeling in a coordinated interagency and intergovernmental framework is the only way to attain restoration, but requires special effort and application of personnel and supporting resources to achieve.

- Models currently existing or under development are not broad enough in geographic scope to meet region-wide ecosystem management needs. This is true of the water management model, the natural systems model, the landscape model, and the wading bird models, all of which need to be expanded to provide region-wide perspective. For instance, present models are not broad enough to observe that a proposed water management strategy may decrease feeding opportunities in one part of the region but increase them somewhere else--and then, to determine the overall consequences of the changes for resident wading bird populations. As another example, one cannot readily see what happens to water levels in Lake Okeechobee when the system is operated to restore near pre-drainage flows to Florida Bay.

- Restoration management using the adaptive management approach will be heavily dependent upon simulations from models, particularly hydrologic models. Yet no one experienced with the most suitable current hydrologic models, South Florida Water Management Model (SFWMM) and Natural System Model (NSM), has been assigned to make simulations specifically for the interagency restoration effort.

- 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 used complementarily, but modeling is not well integrated with present research, and funds for modeling do not usually include sufficient funds for special supporting studies, including verifications.

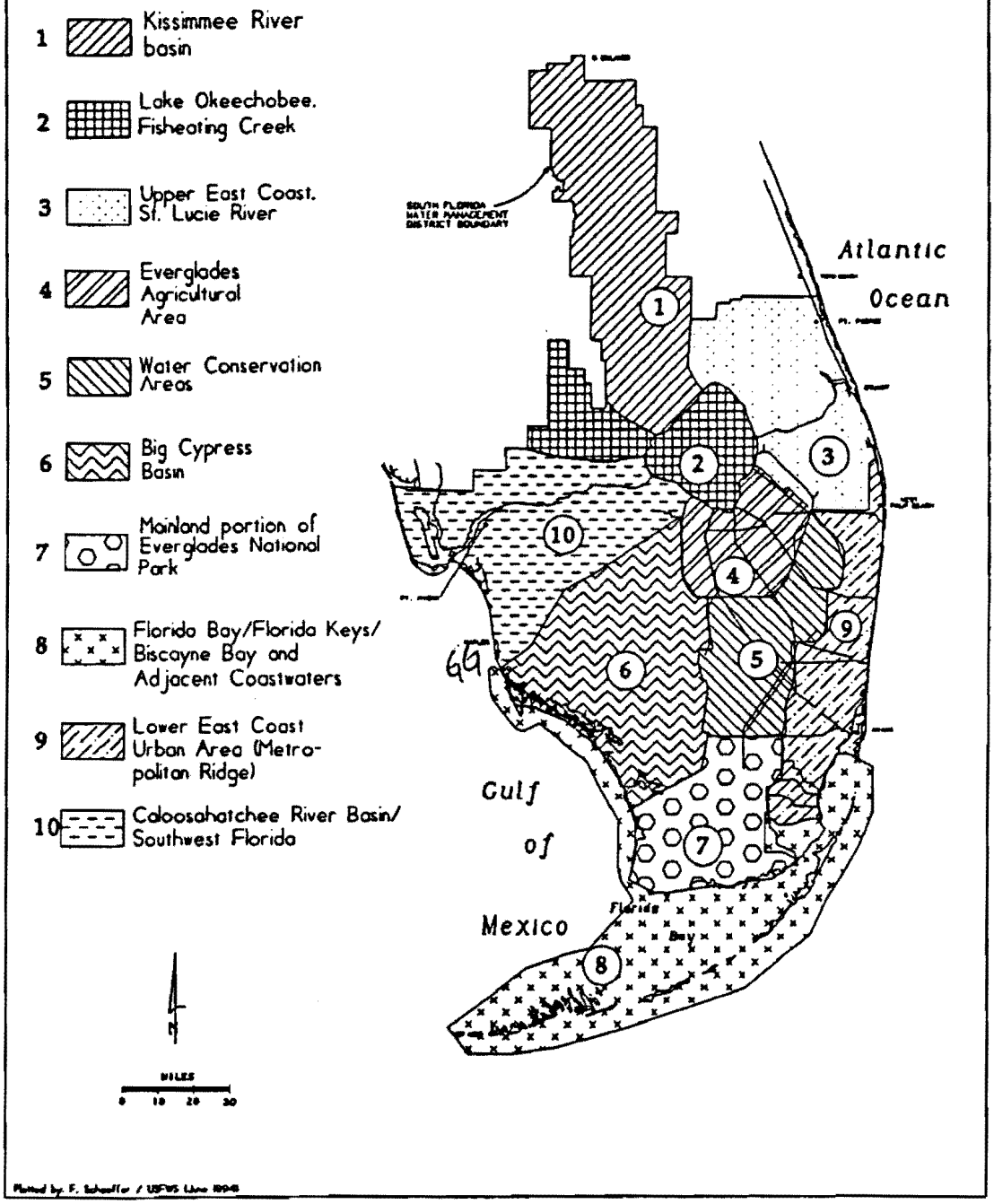


Figure 1. **SUB-REGIONS FOR REVIEW OF ACTIONS TO RESTORE ECOSYSTEMS IN SOUTH FLORIDA**

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

- Certain key species or communities that might be suitable ecological indicators because of their important roles in the ecosystem or their sensitivity to anthropogenic changes are so poorly studied that they cannot be used as indicators. Furthermore, lack of knowledge about the response of these species or communities to hydrologic 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, there are critical activities needed at early stages in the restoration process that are being neglected for lack of directed resources.

- Critical linkages between subregions are not being adequately addressed within agencies. For instance, 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 the decline in this system. Yet the models and supporting measurements and special studies to estimate freshwater inflow to Florida Bay are not being given high priority relative to other issues.

- Issues of agency authority are at times a barrier to focusing efforts at problem sources. Control of harmful non-indigenous 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 control and research initiatives, which appear confined primarily to control of aquatic weeds, Melaleuca, 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 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 the decline of Florida Bay fisheries, the elevated mercury concentrations in fish and alligators in the Everglades, and the 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 potential consequences of developing in wetlands. A scientifically based analysis is needed to demonstrate alternative futures under various land and water configurations.

BACKGROUND

Water is life for South Florida's human and natural systems. Clean, abundant water was a fundamental characteristic of the original South Florida System. The increased human population and human activity in South Florida have brought with them not only an increased need for water but also deterioration in water quality and a decrease in water supply. The latter was caused by the 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 the 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 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 restoration research is that which determines how to modify the structure and operation of the hydrologic system to accomplish restoration. Some systems (i.e., uplands) may, however, require a 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 that restoration goals are to regain. Therefore, the natural hydrologic system, as reconstructed with 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, will result in changes in the ecosystem in the right direction--toward a sustainable healthy state.

Landscape and ecological models, linked to the output of hydrologic models, can help determine the key features of the natural hydrologic system that were most important to sustaining a healthy ecosystem. Scientific investigations to support the restoration, as described throughout the Science Plan, 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 Central and Southern Florida (C&SF) Project that would recreate the key characteristics of the natural hydrologic system, (4) assessing the hydrologic and ecological results of these modifications, through pre- and post-modification monitoring, and (5) modifying the design to make improvements. Given this approach, adaptive management techniques are particularly appropriate.

Adaptive Management

Adaptive management is a structured, iterative approach that recognizes *a priori* that the information used in making decisions is imperfect and that, as decisions are implemented, a structure must be in place to gain better information and to make adjustments in the implemented action. This structure consists of models, special studies, and monitoring, used as coordinated, supportive tools. Models provide a framework for special studies that lead to the development of better information. This information is then used to propose alternative actions. Once an alternative is implemented, monitoring is used to evaluate the consequences. Models help interpret monitoring data, and this information can be used to design better management strategies, as well as better models. Feedback to both scientists and managers will be a key component of the adaptive management strategy, as applied in South Florida. All three elements--monitoring, modeling, and special studies--are critical to successful restoration.

Periodic assessment is the operational foundation of the adaptive management strategy. In adaptive management, models and monitoring are applied within the framework of an assessment protocol. The protocol helps focus monitoring efforts and define how models will be applied at various stages in management. Development of an assessment protocol for the South Florida Ecosystem restoration effort will be an evolving process.

In adaptive management, ecological indicators simulated by models are used to evaluate and help select among management alternatives. The same indicators, measured with monitoring, are later used to assess the effect of a management action. Ecological indicators, to be effective, must be practical and sensitive and capable of being both monitored and modeled. A start toward defining ecological indicators for use in restoration assessment has been made by the Science Sub-Group (1993). Assessment indicators also have been presented by the South Florida Water Management District (1993) and Hoffman (1994).

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 research. Scale and resolution in monitoring should be coordinated with scale and resolution in modeling.

Monitoring

Long-term monitoring is essential to the adaptive management process. Only monitoring can systematically reveal the results of management actions, once they are taken. Routine, systematic surveys of data pertaining to certain ecological indicators will allow managers to evaluate the degree to which restoration is meeting its stated goals and objectives. Monitoring also helps document baseline conditions, including seasonal and year to year variation. Monitoring will provide necessary information for fine-tuning assessment models.

Development of the scientific information needs was the necessary first step in developing a coordinated monitoring program because monitoring plan development will be better focused once the information needs are identified. Special studies will help to better utilize monitoring data. Development of a comprehensive system-wide monitoring plan in conjunction with an assessment protocol will be the next step in the restoration-science coordination effort.

There currently are many on-going and planned monitoring programs by governmental and nongovernmental agencies throughout the region. For instance, a proposal was prepared for development of a prototype monitoring program for the national parks and preserves in South Florida (Everglades National Park et al. 1993). Coordination of these efforts can ensure that there is consistency across efforts in terms of spatial and temporal resolution and covered parameters and that there are no relevant gaps. Coordination also will ensure that data pertaining to ecological indicators are collected. Evaluation and coordination of the various monitoring programs and their integration with the South Florida Ecosystem Restoration Science Plan is absolutely imperative.

Geospatial data is particularly critical to the South Florida Ecosystem restoration effort. A logistic and political process to integrate geospatial information over the region will help ensure the availability of high quality geospatial data. As a first step at integration and coordination among the various interested agencies, representatives from the Science Sub-group, the Federal Geographic Data Committee (FGDC), the Florida Department of Environmental Protection, and the South Florida Water Management District have jointly arranged workshops to encourage the coordination, sharing, and mutual archival of all geospatial information regarding the Kissimmee-Okeechobee-Everglades watershed. 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 will be useful in identifying data gaps in terms of geographic areas and types of information not covered. They will highlight opportunities for further coordination and resource sharing (e.g., NBS-GAP, NOAA C-CAP, NWI Wetlands, and Florida Game and Freshwater Fish Committee Integrated Habitat Plan).

Modeling

Models are another critical component of the South Florida Ecosystem restoration process. Models must be used to establish targets, select among alternatives, and interpret monitoring information to assess progress toward the targets. Modeling activities will involve the design of new models or adaptation of existing models in the following categories: 1) models of physical processes (hydrologic, hydrodynamic, transport, and meteorological

models), 2) ecosystem models (landscape and ecological models), 3) nutrient models, and 4) models of the movements, chemical transformations, and bioaccumulation of contaminants such as mercury. One important task will be to integrate the models into an interactive modeling capability.

An integrated hydrologic modeling system covering the entire South Florida Ecosystem, developed from existing sub-regional models, is a major need of restoration science research. The output of hydrologic models must drive all other types of models that will be developed. The hydrologic models will support model-based research related to natural resource rehabilitation, as well as agricultural and urban sustainability. Critical components of the hydrologic modeling system will be "natural systems" hydrologic models. These 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 provide an objective view of the structure and function of the predrainage hydrologic system. Results of the natural system model of Fennema et al. (1994) have been very useful in gaining perspective on how the hydrologic regime has been altered and establishing targets for hydrologic restoration to support restoration of the ecosystem. Because of the elevation changes in the Everglades that have occurred due to subsidence of organic soils, predrainage topography has been reconstituted for the natural systems models to replace present topography and is being used in the most recent simulations.

Ecological models, including landscape models and population and individual-based species models, are necessary to make hydrologic information meaningful in terms of assessing ecological effects. Since the landscape influences water flow and is subsequently shaped by it, hydrologic and landscape models should be linked to allow two-way interactions so that the effect on water flow of longterm processes such as soil building and landscape pattern formation can be followed. Individual-based species models can show how changes in hydroperiods and hydropatterns may affect reproductive success of populations such as colonial nesting wading birds. Because the foraging area of these species is so broad and foraging success is closely coupled with hydrologic patterns, modeled trends in abundance and recruitment in these populations will reflect trends in ecosystem function. Statistically based habitat association models can be used to evaluate potential species responses to various conditions of changing hydropatterns, hydroperiods, and vegetation types.

Estuarine hydrodynamic models can translate the output of hydrologic models into salinity and circulation patterns in estuaries. By making this connection ecological models and supporting studies can be used to determine how proposed modifications in the C&SF Project will affect estuarine resources in Florida Bay.

A hydrodynamic model for Florida Bay can help scientists evaluate impacts of Florida Bay waters on the reef tract and show the specific environmental conditions that lead to intrusions of high salinity water or algal bloom water from Florida Bay onto the reefs. Although the initial focus is on Florida Bay, hydrodynamic models and supporting studies also are needed for other estuaries.

Fine-scale hydrodynamic and transport models enable the movement of nutrients and contaminants such as mercury in freshwater wetlands to be followed. Such models are an important accessory to water quality models.

Meteorological modeling can improve the grid of rainfall estimates needed as input to hydrologic models. South Florida's rainfall is so spatially variable that the current monitoring network may not adequately reflect the spatial pattern. Surface water and soil moisture influence rainfall and are required inputs to the meteorological model. Therefore, the meteorological model can eventually be used to (a) determine the extent to which the C&SF Project and its predecessors may have affected South Florida's rainfall and (b) evaluate restoration alternatives for their potential effect on rainfall. This will require linking the meteorological and hydrologic models so that two-way interactions can occur.

Research currently underway at the South Florida Water Management District is a vital component of this Science Plan. The existing hydrologic models (SFWMM and its natural system corollary NSM) that will be the core of the proposed hydrologic modeling system were developed by the District and already are undergoing

considerable upgrading that will make them even more useful in restoration modeling. The District also is developing a landscape model (Everglades Landscape Model [ELM]) that could be expanded in scope to be extremely useful to the restoration effort. The District is engaged in other modeling, monitoring, and process-oriented studies in support of the Surface Water Improvement Act (SWIM), the Everglades Forever Act, and the Settlement Agreement. These efforts are focused primarily on resolution of water quality problems, particularly phosphorus. We propose integration of District activities with federal efforts into a comprehensive South Florida Ecosystem Restoration Science Plan.

Special Studies

Several agencies are planning or already engaged in special studies that will support the restoration effort. Some of these are briefly described in sub-region and special topic sections. From the standpoint of the ecosystem restoration effort, the most useful will be 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.

In this context, there is a compelling need to learn more about native wildlife populations and vegetation communities, particularly as it relates to their responses to hydrologic conditions and catastrophic events. Several special studies are being undertaken in conjunction with modeling to provide useful information for designing, refining, or quantifying models (i.e., hydrologic, meteorologic, hydrodynamic, ecologic).

Species and communities that play especially important roles in ecosystem function are appropriate subjects for ecological assessment indicators, especially if they are 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 having different requirements with regard to hydrologic regime. The American alligator, which has another set of requirements, might be another complementary addition to this selected group. Species that are indicators of region-wide ecosystem function would be particularly useful. For instance, 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 their 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 research attention has been given in the past so that both time series of data and an intellectual basis for model design are available. But other key species or communities should be identified for new research that will allow use of their responses 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 are also seriously understudied.

The periphyton community makes up as much as one 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.

Special studies should be conducted regarding species of special concern, particularly those species listed as threatened or endangered. The large number of endangered and threatened species within the South Florida Ecosystem reflects loss of habitat and alteration of ecological processes. Fifty-four plant and 51 animal species within the region are listed or candidates for listing under the federal endangered species act. Additional species

are listed as rare, threatened, or endangered by the Florida Game and Freshwater Fish Commission, Florida Natural Areas Inventory, and Florida Committee on Rare and Endangered Biota. Special concerns for additional species are raised by these groups. Better information about these species will make recovery of these populations as part of ecosystem restoration more likely. Research topics directed toward recovery of these species are given in Table 1.

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 the effects of natural variation on aquatic communities from the effect of human interference. Surprisingly little is known about the community structure and energy-flow pathways of South Florida's aquatic systems and their responses to changes in environmental conditions. The trophic pathways leading to the 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. Information needs, by species and category, for species of special concern are presented in Table 2.

Special studies should support modeling to enhance the usefulness of the models to the restoration effort. Models become more effective over time as relevant information concerning input and design modification is acquired. A list of special studies particularly needed in associated with critical modeling work is given in Table 3.

Evolving Mutually Supportive Human and Natural Ecosystems

The management goal is to recreate the overall hydrologic support functions that, prior to drainage, the lands now occupied by urban and agricultural areas provided to South Florida's remaining natural areas while, at the same time, improving quality of life for human populations.

The increased human population and human activity in South Florida have brought with them not only an increased need for water but also a decrease in water supply and deterioration in water quality. Issues of land use, routing of stormwater runoff, and disposition of treated waste water all relate to concerns for human water supply. Loads of nutrients, various contaminants, and total organic carbons associated with human alterations of the systems relate to water quality. Several proposed science plan topics address these problems.

Water quality is affected by land use and the practices of individuals and industries. Finding a harmonious balance between human populations and the natural ecosystem in South Florida requires resolution of major issues concerning the release of nutrients and contaminants into surface and ground waters. The Everglades Settlement Agreement, the Everglades Forever Act, and the Clean Water Act mandate that threshold concentrations be determined for effects of phosphorus on the ecological balance of native flora and fauna. Research can show how best to reduce the input of nutrients at the source and by passage through wetland water treatment areas.

Contaminants are another serious water quality concern in South Florida. Mercury has generated a great deal of notice because of the human health hazard associated with its observed bioaccumulation in fish and higher organisms. A separate section of this report is devoted to the complex mercury issue. Other contaminants 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 extremely important within the South Florida Ecosystem. Many of the pesticides (i.e., 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. 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).

Water quality can be affected by water management. Take for instance, the trihalomethane problem in some South Florida drinking water. 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 dissolved organic carbon (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. DOC is released into South Florida's waters by the oxidation of drained organic soils and by the proliferation of algae and aquatic weeds in canals. Although there are technological methods for reducing the contamination of drinking water with chlorine byproducts, these solutions all have their problems. 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 that it can be used during the dry season. Land use decisions ultimately affect the amount of water that will be stored on the land and in surficial aquifers. As more and more land becomes developed, recognizing 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 becomes more important. Some of the proposed research deals 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 the 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 level and site-specific level.

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. This continued loss of soil depth is a severe agricultural concern that limits the lifetime of agriculture in the area. The 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 research program is proposed with the objective of developing the technology for this zero subsidence system. It is possible that successful research would help modify the hydrologic function of the EAA, with respect to downstream natural ecosystems, to more closely resemble the hydrologic function of the area prior to drainage (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 the release of wet season rainfall.

OBJECTIVES

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

RECOMMENDED APPROACH

- **Projects specifically organized around modeling should be funded sufficiently to allow these projects to finance related special studies involving field and/or laboratory work.**

The best results are achieved if the modeling is initiated at the beginning of the project rather than at the end and if special studies are included with modeling.

- **Establish groups to model the hydrologic, hydrodynamic, landscape, meteorologic, and ecologic processes of the South Florida restoration area, taking into account existing models. (Lead--Science Sub-group)**

The first step will be development of a hydrologic model for the South Florida land base. Existing models will be upgraded and new ones developed for areas not yet covered by hydrologic models. Hydrologic models will provide input for hydrodynamic models being developed to predict circulation, mixing, and salinity patterns in Florida Bay as a function of freshwater inflow and other variable factors. The set of models will consist of a three-dimensional model for Florida Bay, quantified for 2-D operation until sufficient data to support 3-D operation can be obtained, and a regional numerical ocean circulation modeling system that can provide boundary conditions for the Florida Bay model. Ecological models that relate species, populations, communities, and landscapes to the simulation outputs of hydrologic or hydrodynamic models will provide an objective way to evaluate alternative water management strategies for their potential effects on the ecosystem.

- **Establish a set of ecological indicators, starting with the assessment criteria recommended in Science Sub-Group (1993). (Lead--Science Sub-group)**

Refine the original list of assessment criteria into a set of practical and sensitive indicators in coordination with the planning of modeling and monitoring activities. Select species and communities that play major roles in ecosystem function. Select several subjects, each with a different set of habitat requirements and representative of a larger group. Give priority to species or communities that are indicators of region-wide ecosystem function. Initially, use those species and communities for which information and time series of data are available. Take into consideration the information that can be generated by models presently under development. Suggest research that could improve the use of the indicators.

- **Propose potential ecological indicators for which little information is available and target these species or communities for special research attention.**

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.

- **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--Science Sub-Group)**

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 the preparation of a monitoring plan, and modelers and those involved in developing the monitoring plan should take part in preparing the assessment protocol.

- **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. (Lead--Science Sub-Group)**

Comparison of the present system with the predrainage system is important to developing restoration targets. The best guide for understanding the ecological ramifications of the changes in spatial extent and hydrologic conditions that have occurred from predrainage days to present is the simulated output of spatially explicit "natural system" hydrologic models supporting a system of ecological simulation models that operate at several scales. Natural system hydrologic models are versions of water management models in which the control structures have been removed and the topography restored to approximate the predrainage system.

- **Initiate ecological model development at the beginning of the restoration effort and integrate it with the 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 to illustrate why this information is needed. By developing ecological models concurrently with the hydrologic and hydrodynamic models to support them, scientists can ensure that the hydrologic and hydrodynamic models will provide suitable support for addressing ecological questions.

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

Initiate modeling at the beginning of scientific studies rather than at the end to help insure that 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.

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

Conduct special monitoring-related topic workshops, such as the geospatial 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.

- **Develop the information base for application of the adaptive management approach, emphasizing the building of understanding and assessment capability. (Lead--Science Sub-group)**

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. Emphasize gaining a better understanding of how vegetation communities and wildlife are affected by hydrologic regime, anthropogenic nutrients, and contaminants. Focus especially on species and communities that are the subjects of proposed ecological indicators to be used in making assessments. Utilize the workshop approach for bringing together the appropriate parties, including modeling and monitoring participants, as well as the management community.

- **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 landuse configurations? What landscape combination will allow healthy natural systems and urban and agricultural systems to coexist?

- **Develop technically sound landscape-level wetland functionality assessment methods that can be used by wetland regulatory and planning programs as a basis for making appropriate decisions.**

The landscape-level wetland assessment method must be developed and implemented for all wetlands within the SFWMD boundary during the development of the South Florida Wetland Conservation Plan by 1996. 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.**

Presently there are a number of different approaches 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 methods 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.

- **Conduct mesocosm studies to establish response thresholds for phosphorus concentrations.**
  Examine ecological balance in native flora and fauna in relation to phosphorus concentrations in inflowing waters.

- **Track the progress of restoration using a monitoring approach that relates concentrations of chemical contaminants in surface waters, sediments, and biota with known water quality, sediment quality, and tissue residue standards based upon toxicological standards.**
  The toxicological guidelines should be used in conjunction with contaminant monitoring to establish current "status and trends" in environmental conditions and to track the success of various management actions as they are taken.

- **Devote some monitoring and modeling attention to short-term events, which may discharge large concentrations of nutrients, suspended sediments, and chemical contaminants into surface waters and coastal waters.**
  Experience with pesticides in South Carolina has shown that one 8-hr discharge of pesticides per year may result in a more than 90% decline in estuarine tidal creek productivity (G. Scott, National Marine Fisheries Service, Charleston Laboratory, pers. comm.).

- **Develop a set of benthic testing species for sediment toxicity for use in South Florida.**
  The benthic indicator species presently used by EPA and the Army Corps of Engineers are temperate zone organisms.

- **Provide continuous support as an integral part of restoration operations budgets for this multi-year adaptive management effort. (Lead--?)**
  Adaptive management for ecosystem restoration requires continual predictions and feedback from the interactive modeling, monitoring, and research efforts--and thus, continuous support.

- **Ensure resources to support the planning, coordination, and oversight activities of the Science Sub-Group. (Lead--ITF)**
  A special annually replenished fund should be made available for Science Sub-Group 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).

- **Prepare flow charts showing critical nodes and pathways in the development of information for ecological restoration, including building knowledge and providing assessment tools. (Science Sub-Group)**
  Such flow charts will help prevent needless delays in the restoration effort. For instance, a hydrodynamic model for Florida Bay will help determine the relationship between freshwater inflows and salinity and circulation patterns. A critical input to the hydrodynamic model is estimates of flow and measurements of salinities, including a perspective on the pre-drainage condition. The SFWMM and NSM models do not currently 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 the models and preparation of finer resolution versions of the models are critical first steps to understanding relationships between freshwater flow and Bay salinity and circulation patterns. Preparation of finer

resolution versions of the current models is a planned project of Everglades National Park hydrologists but has not been done due intensive assessment responsibilities and lack of personnel.

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Table 1. Proposed special studies.

Recover Populations of Rare, Threatened, and Endangered Species:

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

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

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

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

- Identify potential pathways for new introductions.
- Determine factors that influence the susceptibility of faunal and flora communities to exotic invasion.
- Develop environmentally "safe" biologic controls for exotics.
- Identify nonnative 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 intended to assess the impact of restoration efforts on 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/Amphibians				
Sea Turtles		X		X
American Crocodile	X			X
Alligator	X	X		X

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

Wading Bird Studies

- Systematic Reconnaissance Flights (SRF)
- 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 Invertebrates

- 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

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

Mammals

- Range expansion of feral pigs
- Census of declining species

Non-indigenous Animal Species

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

Substrate profile studies

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

Support landscape model development

- Landscape/vegetation/soil (NBS)
- Gradient analysis (NBS-G)
- Topographic surveys (NPS, USGS)
- Succession models (macrophyte/periphyton) (NBS-G)
- Soil surveys/topographic surveys

Support integration with faunal models

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

Threshold studies

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

Monitoring

- SWIM and Everglades Forever required monitoring (SFWMD)
- Restoration assessment monitoring (success measures) (NBS, NPS, FDEP, ACE)

Florida Bay

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

MODELING HYDROLOGIC PROCESSES

INTRODUCTION

Overall hydrologic objectives required to achieve ecological restoration have been stated as follows:

A. Restore sheetflow.
B. Restore strong hydrologic linkages between areas.
C. Eliminate or reduce barriers.
D. Restore the dynamic water storage capacity of the system.
E. Restore the natural fundamental relationships of ground and surface water levels and water flow with rainfall.
F. Restore a more natural quantity, timing, location, and quality of freshwater flow throughout the system and into estuaries.
G. Prevent point and non-point airborne or waterborne pollution, including contaminants, excessive nutrients, sediments, and thermal pollutants.

The fundamental steps of the hydrologic research plan that will help guide restoration of the above hydrologic characteristics are as follows:

1. Characterize natural hydrologic structure and function
2. Assess present-day conditions
3. Formulate specific restoration objectives that consider natural system requirements and societal demands.
4. Develop and evaluate alternative strategies for achieving the objectives.
5. Implementation (structural and operational)
6. Define success criteria
7. Evaluate implementation consequences using success criteria.

Hydrologic models are critical to most of these steps. For instance, only hydrologic models can provide a quantitative view of what predrainage patterns of water flow and hydroperiod in relation to rainfall might have been like. Only hydrologic models can provide the freshwater inflow data that hydrodynamic models require in order to access affects of freshwater flow on salinities and circulation in Florida Bay and other estuaries under various water management scenarios. Ecological and landscape models of freshwater wetlands and estuaries will only be useful in evaluating alternative water management strategies if they receive input from hydrologic models.

Improvements in existing hydrologic modeling capability are necessary in order to adequately support a scientifically based restoration program and provide useful input to other types of models. The proposed hydrologic modeling effort has three parallel tracks: model improvement, model development, and model application.

The first step in the hydrologic modeling effort will be to develop a hydrologic modeling system that covers the entire South Florida Ecosystem landbase. In the immediate term, existing models will be upgraded, models will be developed for areas not yet covered by appropriate hydrologic models, and the models will be integrated with one another. Model upgrading will be accomplished with improved algorithms, parameters, and data, modular codes, and new code that will make it possible to test alternative structural configurations and operating procedures without changing code (i.e., making the changes through data bases rather than within the program). Graphical interfaces that provide preprocessing and postprocessing capability and make it easy to summarize and analyze input and output also will be constructed. Initial integration of the models will be accomplished simply by standardizing input and output data parameters and formats. Some of these improvements are already underway.

There are several areas for which there no adequate existing models. Spatially explicit models that include both surface and ground water do not presently exist for southwest Florida. Existing models do not have the topographic detail needed to adequately model freshwater flows to estuaries. Therefore, more detailed models for the coastal areas are needed. Such a model is particularly important to determining how to establish a more natural timing and volume of freshwater inflow to Florida Bay.

At the same time existing models are being improved, a more advanced and comprehensive modeling system will be developed. These models will use new programming languages and support systems that have greater capability than those used in present models.

Process studies and measurements are needed to improve algorithms and parameters such as evapotranspiration, flow resistance, levee leakage, and seepage of groundwater into canals in existing hydrologic models.

Parallel with model development, the current monitoring network will be upgraded to improve present flow estimates and expanded to cover areas that are not presently covered, such as surface flows to Florida Bay and many west coast estuaries. Groundwater flows to Florida Bay also need to be determined. Monitoring provides baseline data and data to assess responses to operational changes and is critical for model testing and refinement.

BACKGROUND

The Central & Southern Florida (C&SF) project was authorized by Congress in 1948 and is a complex system which manages the surface and ground water resources to serve a variety of interests. The project primarily serves flood control and water conservation purposes. The area's natural ecosystems have been substantially altered by human activities. There has been increasing concern over South Florida's continued rapid growth and the effect of structural and operational changes in the hydrologic system related to land use changes and increased water consumption. There is particular concern about the Lake Okeechobee, the Water Conservation Areas, the Big Cypress, and Everglades National Park ecosystems, including Florida Bay, which are severely stressed. The complex nature of both the hydrologic system and the ecosystem it supports has made it difficult to evaluate the effect of changes in the structure or operation of the C&SF project and the effects of other human activities. The South Florida hydrologic modeling system can be used to (1) gain a better quantitative understanding of hydrologic processes, (2) evaluate proposed structural and operational changes, (3) guide day to day operations, (4) identify data gaps and research needs to improve our quantitative understanding of hydrologic processes, and (5) provide a conceptual framework to interpret, extrapolate, and illustrate data from monitoring programs.

The hydrologic modeling system, by providing surface and groundwater flows as well as water depths, is the foundation on which will be built, through interfaces, water quality and transport models to follow the dispersion of nutrients, contaminants, and sediments; hydrodynamic models to generate the salinity and circulation patterns of estuaries in relation to freshwater inflows as well as regional oceanographic processes; meteorologic models to generate rainfall as a function of local surface moisture features as well as large-scale climatic factors; and models to represent ecological processes at many scales. Needed is the capability to address both short and long term management issues for both specific areas and the region as a whole. Therefore, a system of hydrologic models must be designed that will adequately simulate processes at multiple spatial and temporal scales.

This simulation modeling system will provide a framework for interagency exchange and integration of ideas, data, and modeling efforts. The assembly of improved knowledge and the interchange of objective analytical concepts and techniques among hydrologic researchers, resource managers, and development regulators can be expected to significantly improve system management procedures and technical coordination among agencies with management and regulatory responsibilities in the South Florida Ecosystem.

ISSUES AND PROBLEMS

Hydrologic models are needed to address issues related to water use and water needs by agriculture, urban and industrial areas, and ecosystems. These models are needed to address issues concerning the water redistribution in time and space: for instance, drainage of wetlands for agricultural or urban uses, flood control in urban and agricultural areas, changes in hydroperiods and hydropatterns in remaining wetlands, and changes in the quantity, timing, and distribution of freshwater flows to estuaries.

Some problems related to these issues are as follows:

South Florida has experienced unprecedented economic growth in recent decades with subsequent development and alterations of natural systems. This rapidly growing population and associated economic activities are placing progressively increased demands upon the limited water resources of the Everglades.

Land use changes being allowed by governments are causing development to encroach into wetlands, diminishing both ground and surface water storage, thereby reducing the water supply. Shallow aquifer systems provide major water supplies. Anything adversely affecting these aquifers has far-reaching effects.

Management to control flooding of low-lying areas in wet years has had a devastating effect on water supplies, wetland systems, and estuaries during dry years.

Saltwater intrusion, the inland shift of the fresh/salt interface, has been caused by a general lowering of the water table. Several of the municipal water supply wells located along the coast have been abandoned and many others are threatened by salt water contamination. Saltwater intrusion is not only an urban problem, but also a problem for natural ecosystems. The landward spread of mangroves at the northern end of Florida Bay was caused by saltwater intrusion and has been accompanied by a loss of freshwater marsh.

Because the location of the fresh/salt boundary is a function of the difference between the water table and sea level, sea level rise, a continuing phenomena that has been proceeding at a rate of about 3 cm every 10 years in South Florida, exacerbates the problem of salt water intrusion and may someday threaten freshwater wetlands as well as aquifer water supplies.

Wellfields to supply increasing urban demand are drawing down the aquifer, affecting water supply and decreasing the hydroperiods in nearby wetlands. New wellfields continue to be constructed, especially in the lower east coast areas.

Declines of as much as 35 ft since the 1930's have occurred in the potentiometric surface of the Florida aquifer between Orlando and Lake Okeechobee. The lowering of the potentiometric surface has reduced the groundwater seepage that previously reemerged as surface water contributions to the upper Kissimmee River basin chain of lakes, the Kissimmee River, and Lake Okeechobee.

Drainage, impoundment, and diversion of water has changed the quantity, timing, and distribution of freshwater flow to estuaries. As a result, some estuaries often receive too much fresh water too quickly during the wet season and too little fresh water for too long during the dry season. Others, such as Florida Bay, probably receive considerably less freshwater throughout the year than they did under predrainage conditions and now experience severe hypersaline conditions.

SCOPE

The proposed hydrologic modeling system should be regional in scope so that changes made in one area can reveal resulting changes somewhere else. At the same time, the system should provide the resolution required

to address questions localized changes and effects. At a minimum, the system should consist of regional models and models at a smaller temporal and spatial scale. The models should be capable of being linked and interfaced using compatible formats for input and output. Spatially explicit models should be included in model upgrading and development because spatially explicit models such as grid based models, in addition to providing water flows, provide a grid of water depths that can be used to obtain hydroperiods and hydropatterns. Models should be modified or developed to extend to the coast and simulate freshwater flow to estuaries.

The South Florida Water Management Model (SFWMM) has been useful because it has a relatively broad areal coverage, it is grid based, and it integrates ground and surface systems. The Natural System Model (NSM) is a corollary of SFWMM and represents the system in the absence of canals and other water control structures. Comparison of output from the two models produced with the same rainfall input provides perspective on the characteristics of the natural hydrologic system in contrast to that of the currently existing system. SFWMM and its NSM corollary simulate flows and water levels (both ground and surface) for an area that includes the Water Conservation Areas (WCAs), the Everglades Agricultural Area (EAA), much of the Big Cypress National Park (BCNP), Everglades National Park (ENP), and the Lower East Coast. The model provides differing levels of input or simulation sophistication for all the important processes affecting water management in this area: rainfall, evapotranspiration (ET), infiltration, canal/aquifer interactions, levee seepage, and overland, canal, and groundwater flows.

The SFWMM should be a fundamental component of the hydrologic modeling system. However, in its current form, it has shortcomings. Making improvements in this model should be one major tactic of overall modeling system development. Planned improvements deal with code, algorithms, parameters, spatial and temporal data, and pre- and post-processing capabilities. One major emphasis should be in redoing the code to make it both easier to follow and more flexible. Model revision should allow changes in structure and operations for testing alternatives, including the natural system alternative, to be inserted through a change in an input data file rather than with a change of code.

Another major tactic should be the development of new models taking advantage of new technology and software such as object oriented programming and GIS. A new regional simulation model (SFRSM) will be developed by SFWMD. The new South Florida Regional Simulation Model (SFRSM) will be a completely redesigned version of the existing SFWMM with extensions to simulate the natural system (the region in the absence of canals and other water control structures). It will not be a modified or enhanced version of existing codes of the SFWMM and NSM, but rather a completely new model designed to analyze future regional water management alternatives efficiently. Federal agencies are being asked to become involved in planning and advisory activities associated with the development of this model and to provide funding and technical expertise to the model development effort.

Natural system versions of grid based or otherwise spatially explicit models need to be included in model upgrades and replacements so that the most current model of the present system always has a natural system corollary. Because of the lack of pre-1900 rainfall, stage, or runoff data, natural system models provide the only objective, quantitative perspective on hydroperiods, hydropatterns, and water flows in South Florida in relation to rainfall in the absence of canals and other water control structures. Because the natural system models are executed with the same time series of rainfall data used in the water management model, they show, without the confounding effect of different rainfall patterns, how the structures and their operation have modified system function. These models have been invaluable to ecologists in translating rainfall patterns into hydrologic conditions that supported plant communities and wildlife as they might have done in the predrainage system. As water management models are improved with new algorithms, parameters, and data, the ability of natural system corollaries of these models to simulate the predrainage system can be expected to also improve. Special effort is needed to obtain more detailed near-coast topographic data to better simulate freshwater outflows to estuaries with natural system models.

Other existing models should be evaluated for incorporation into the modeling system to meet various needs. Several hydrological models are currently being applied in South Florida. The South Florida Water

Management District has identified 45 existing models and 26 models under development for application in South Florida. Some are different applications of the same model. Some are models of detailed temporal and spatial resolution such as MOD-FLOW, MODBRANCH, DWOPR, HEC-2, UNET, and CHANOP. These models are being applied to specific problems such as wellfield analysis, pumping sizing, and seepage studies.

Access to the modeling system must be provided to all agencies involved in activities related to the Restoration effort. A central repository for the hydrologic modeling system is needed. Funding and manpower will be needed for the development and operation of the modeling system. We recommend that the Corps of Engineers be the central agency to testify and administer the funding for the hydrologic modeling effort. The work plan and funds for each agency will be decided by the Federal Task Force. A funding request that covers all participating agencies doing hydrologic modeling work is included at the end of this section. The Corps' funding request covers any costs incurred in administering the funds for all involved agencies. The work assignments will be decided by the Task Force through the Science Sub-group and its technical designees. Close coordination with modeling efforts of SFWMD will be necessary.

Extensive interagency cooperation and coordination is needed to successfully develop and operate a hydrologic modeling system. This modeling system will be used by Federal, State, and local agencies involved in various aspects of land water management of the South Florida Ecosystem. Modeling outputs will be formatted in standard formats for postprocessing into standard database and GIS utilities. The central repository will be the Florida GIS Distributed Spatial Data Library (DSDL) being developed by the U.S. Geological Survey. Standard postprocessed spatial information products will be archived in this central GIS repository, which is designed to accept multi-GIS data bases and is accessible through ARCINFO, GRASS, and other GIS software.

OBJECTIVES

The objective is to develop a hydrologic modeling system that can be used to modify or redesign and operate the C&SF Project so that it can support ecosystem restoration while at the same time providing the flood control and water supply needs of urban and agricultural areas. The system should be capable of predicting the impacts of proposed land use changes on both water supply and natural communities and should generate insight on how to modify the structure and operation of the C&SF Project to foster a return to environmental health of the Everglades, the Big Cypress, and South Florida estuaries, including Florida Bay. The hydrologic models should be capable of addressing important resource questions, including but not limited to the following:

- How will restoration changes made in the Kissimmee River affect water levels in Lake Okeechobee and the need for regulatory releases to the St. Lucie and Caloosahatchee Rivers?
- How will proposed changes in the regulation schedule of Lake Okeechobee affect Lower East Coast water supplies and water flow to Florida Bay?
- How has the C&SF Project changed the spatial and temporal pattern of surface water coverage, water depth, and water movement in wetlands?
- How would hydroperiods and hydropatterns in natural areas be affected by various proposed changes in structures or operating procedures?
- How has the C&SF Project changed the volume, timing, and location of freshwater inflow to estuaries?
- How would the quantity and timing of freshwater flow to estuaries be affected by various proposed changes in structures or operating procedures?

- How might planned or anticipated land use changes impact water supply and the ability to manage water for ecosystem restoration?

- How might changes in on-farm water management practices and changes in the structure and operation of the C&SF system to control subsidence in the Everglades Agricultural Area affect the volume and timing of water flow to downstream areas from Lake Okeechobee and the Everglades Agricultural Area?

- How does undeveloped wetland modulate hydrologic exchanges between protected wetlands in the Everglades and the developed east coast?

- How does undeveloped coastal wetland modulate hydrologic exchanges between estuaries and the developed east coast?

Following are the basic components of the proposed hydrologic modeling system. These components will ensure that the most efficient methods are used during the model development phase. The main technical concerns of this undertaking include the extremely large geographic area under consideration, the massive amount of data that will be collected, and the effort needed to organize the data in an efficient manner.

Iterative Model Development Process

Simulation modeling requires some form of fundamental understanding of the variables to be modeled. Basic to the modeling process is the quantification of values for each variable in the model. Quantification requires either empirical data or sets of assumptions based upon fundamental knowledge of each variable's functions. Typical investigations begin with the development of prototype simulations. These preliminary efforts provide means for identifying and organizing essential data. As understanding of variable functions and interactions improve, the simulation modeling process contributes to improved knowledge on the hierarchical, temporal, and spatial aspects of each modeled variable.

Geographic Information Systems (GIS)

The modeling system should use a GIS input and output shell to provide linkages between the different models, help interpret simulations results in a spatial context, and make the system "user-friendly." Linkages will be required between the databases, models, and the GIS shell.

GIS technology allows for the generation of new spatial data through the comparison and analysis of multiple spatial themes. To accomplish this creation of new data, most GIS systems share a conceptual model that differentiates spatial elements into layers or themes, such as vegetative cover, soil types, land use zones, slope types, etc. These themes are represented in various formats, such as arcs/nodes, polygons, grid cells and triangulated networks. GIS organizes information about both the spatial location and the value of each unit in a data layer, so that new data can easily be derived when two or more layers are compared.

GIS allows the user to store, manipulate, and analyze large volumes of cartographic data that would be cumbersome using conventional methods and helps in developing an easily updated resource database. GIS can be used to develop land-use, soil-group and sub-basin boundary maps.

The models must be integrated in a manner that minimizes the effort required for application and interpretation. GIS provides a means to accomplish some of the interfacing. A GIS could be used to import and couple input data to the models and provide graphical display. Most GIS software can reside on current and anticipated new generation microprocessor workstations. Unix-based workstations with powerful graphics capabilities facilitate linkage of models, development of user-model interfaces, and development of highly versatile graphical output options. For these reasons, the modeling system must be GIS based.

Hardware and Software

In order to ensure that this modeling system is available to as many agencies, groups and individuals as possible, the hardware and software systems need to be designed to be as compatible as possible with existing systems. Therefore, the modeling system should be designed to run on microcomputers or workstations and software should be compatible with systems currently used by the SFWMD, the National Park Service, USGS, U.S. Army Corps of Engineers, EPA, NOAA, and other agencies and interest groups working in South Florida.

APPROACH

Modify, Enhance, and Apply the South Florida Water Management Model (SFWMM) and the related Natural Systems Model (NSM)

Several modifications and enhancements should be made to the SFWMM to improve and extend its performance and utility. A 2-step approach is recommended. First, the existing SFWMM should be improved to allow for its relatively immediate use in water quantity decision-making. Secondly, and concurrent with, the modification of the existing SFWMM, major enhancements to the SFWMM are proposed. Once completed, most of the water quantity issues for the freshwater system could be answered within a single modeling framework.

Support and improvement of the SFWMM includes the improvement of information used in the model. Some of the more important information needs are:

1. Water is lost at the salinity control structures due to seepage losses from project storage areas along the more than 170 miles of coast. Seepage loss rates are estimated to range from 2 cfs/ft head/mile in the northern areas to 5 cfs/ft head/mile in the southern areas.

2. Evapotranspiration is a major pathway for water leaving the system. ET may vary spatially as well as temporarily because of vegetation and microclimate variation. ET has been poorly studied considering its importance to the overall water budget.

3. Groundwater flow and levee seepage losses from the Water Conservation Areas are significant, but poorly quantified. Seepage losses through and under levees range from 4 to over 100 cfs/ft head/mile of levee. The higher seepage losses occur along the exterior levees bordering WCA 3B, where the levee coincides with a highly permeable segment of the Biscayne Aquifer.

4. Surface freshwater discharge to the East Coast via canals is poorly estimated for 19 of the 25 canals discharging to the East Coast. Data collection and analysis need to be performed to properly calibrate flow rates to stage in the remaining canals. Recalibration may allow historic discharge time series to be reconstructed from historic stage data.

5. Estimates of both surface and groundwater flows to Florida Bay are needed.

6. Many of the canals discharging fresh water to the lower southwest coast are not calibrated or monitored.

Develop and Apply Groundwater-Wetland Models

Development of fine resolution groundwater/wetland models is needed to address site-specific questions in several sub-regions whose hydrologic regimes are dominated by wetland/groundwater interchanges (such as the WCA's, the EAA, or the Lower East Coast well fields). These models will answer local questions, such as the effects of large-scale groundwater pumping or lowered within Dade County on the hydrology of the C-111 basin, detailed distribution of flows delivered to the Loxahatchee Wildlife Refuge and ENP, as well as the distribution of

flows within the EAA. The need to evaluate salinity intrusion within the Biscayne Aquifer will also require more detailed groundwater modeling capabilities than those proposed for the SFWMM.

Groundwater model development will require extensive field data collection to establish a more definitive database on subsurface stratigraphy and transmissivities, particularly in the vicinity of canals. Applications of the models developed will center on evaluation of the effects of operational water delivery changes on coastal salinity intrusion, the effects of the large well fields being implemented in Dade county, and connections between ground water and major wetlands.

Software for Routine Calculation of Water Budgets from Model Input and Output

A water budget for the South Florida hydrologic system is essential to identify the major sources and sinks of water, determine locations where inadequate data exist, and provide a fairly concise estimate of the actual magnitude of water available in the system. The modeling system should be capable of generating a water budget that shows the magnitude of inflows and outflows for the region as a whole as well as subregions. It should be possible to model the effect on the water budget of proposed modifications in C&SF Project structures or operations. Comparison of water budgets for the natural and current systems would provide insight on the effect of anthropogenic influences. The capability to routinely produce water budgets should be a basic feature of the summarizing and integrating software.

Develop Interfaces to Link Hydrologic Models to Other Models

Hydrologic models must support other types of models in order to provide effective support for ecosystem restoration. Other types of models for which hydrologic input is needed include hydrodynamic, meteorological, landscape, ecological, and water quality models. One of the most important needs from a hydrologic modeling system is to simulate freshwater flows to estuaries for use as input to hydrodynamic models. The hydrodynamic models can then demonstrate how various water management scenarios would be expected to affect estuarine salinity and circulation patterns. For meaningful assessments of effects of alternative scenarios on testable biological success measures, hydrologic models must provide input to landscape, ecological, and water quality models.

Hydrologic models used in conjunction with water quality models may also have to be linked to hydrodynamic and transport models in order to provide realistic information on sources, sinks, transformations, and transport of nutrients or contaminants. A meteorological model is being developed to provide improved rainfall estimates for hydrologic modeling. It requires information on surface water coverage and soil moisture that can best be provided by the hydrologic model. The meteorological model, if provided with simulated information on surface water coverage and soil moisture, could provide insight on how alternative water management scenarios might affect rainfall.

Since both the landscape and rainfall patterns affect the hydrologic regime, two way linkages should be developed between hydrologic models and the landscape and meteorological models. Model linkages will make it possible to evaluate how various hydrologic system configurations and operations will affect the whole system.

Develop and Apply Dynamic Routing and Watershed Runoff Models for Inflows to Lake Okeechobee

Dynamic river routing and field-level watershed runoff modeling capabilities are needed within and along the Kissimmee River System (KRS), Fisheating Creek, Taylor Creek, and Nubbins Slough. A Kissimmee River model is particularly needed because the restoration project in progress in the Kissimmee basin may affect water levels in Lake Okeechobee.

Technology Integration, Maintenance, Application, and Distribution Tasks

The hydrologic models must be integrated in a manner that minimizes the effort required for application and interpretation. This integration requires the development and coupling of four types of interfaces: 1) model-

user interface; 2) model-model interface; 3) input data-model interface; and 4) output data-graphical/visualization interface.

Policy, Management, and Coordination

A single group or organization should be responsible for the Federal role in planning and execution of the four tasks described below, which should be the primary mission of this group or organization. The office should be located in Florida and act as a technology center in support of the consortium of agencies involved with the management of the South Florida hydrologic ecosystem. Additional details of the office, such as its staffing, management, and reporting chain, require agreements among participating parties and are beyond the scope of this appendix. They will be decided by the Federal Task Force through the Science Sub-group and its technical designees.

1. Integrate Modeling Components. The integration of the models and tools discussed previously will require the development of four basic types of interfaces: (a) model-user interface; (b) model-model interface; (c) input data-model interface; and, (d) output data-graphical/visualization interface. The model-user interface is the actual environment through which the user accesses various programs, selects program attributes, inputs data, simulates various conditions, and evaluates model output. The model-model interface, which is transparent to the user, includes the essential linkages between various models and their outputs. The input data-model interface is necessary to couple large databases with models, and to allow efficient retrieval of data based on user-selected conditions. Finally, the output data-graphical/visualization interface is critical to presentation of voluminous simulations results in a form interpretable by decision makers, as well as scientists and engineers.

Beyond this interface development, large, but separate, databases must be compiled, integrated, and placed in a single repository for common use. Analogously, the models being developed or adapted within this proposed plan must be compiled and integrated through the above interfaces.

2. Maintain System Components. The investment represented by the models, tools, and databases proposed for development within this appendix will be large. For their effective use over the length of the study and the long term, the technology must be appropriately maintained. Maintenance is much more than providing for locations for data and models to reside. The term includes modification in the event of error identification, the opportunity to benefit from improved technology, or to fulfill additional requirements as they arise. Furthermore, hardware and communications systems must be maintained to allow users to access models and data from remote entry locations.

3. Transfer Technological Products. As the central repository for databases and models, it would be appropriate for the group or organization to also be the primary distributor for reports, users manuals, model user support, etc. Additionally, the office would publish periodic newsletters or information bulletins delineating new available technologies, updates to existing models, errors found in existing models, etc., and respond to requests for various models and data bases.

4. Apply Models. In its efforts to support users and maintain the system, the group or organization should become proficient appliers of the models. Agencies and groups having either in-house or contractor expertise will also be proficient in model application. A hardware and software base must be nurtured to allow the office to apply these codes. These applications will be on a cost-reimbursable basis, with reimbursement coming from the agency requesting the application.

CURRENT AGENCY PROPOSALS

Corps of Engineers

Traditionally the Corps has studied and built projects to solve specific problems. Funding has been limited to a very focused study area and the authorization limited the project scope. In large basins with several watersheds, changing one of the sub-watersheds for flood control can impact functions in other sub-watersheds; i.e., groundwater flow, water supply or even the timing of natural runoff. Faster computers, automated data gathering, and geographic displays have made it possible to include project designs for the larger ecosystems and test for unexpected impacts. In order to build and manage large models, a dedicated work force, isolated from the daily "fire fights", is necessary.

A Hydrologic Modeling Section in the Hydrology and Hydraulics Branch is needed, independent of project oriented operations, that would build and/or maintain large basin hydrologic models. The responsibilities of that Section would be as follows: (1) Development and maintenance of hydrologic models, such as; surface runoff (precipitation/ground interaction) models, water quality (hydrodynamic) models, groundwater surface/ groundwater interaction models, and GIS; (2) Maintain and build data banks for storage of GIS input and output data such as physical basin characteristics, precipitation, discharge, and other data/information needed in the hydrologic models; (3) Coordinate with other USACE Districts and State agencies that have GIS systems for exchange of data and applications; (4) Support Water Management Operations; (5) Support the Regulatory program; (6) Support Environmental analyses; (7) Support Engineering and Planning for plans analyses and project design; (8) Seek new programming applications and modeling techniques; (9) Disseminate new information to users; and (10) Assist in training others in the use of large basin models.

State-of-the-art technology requires continuous training, which needs to be scheduled and funded. Hydrologic modeling requires the interdisciplinary skills of a team. A staff of five (5) would be needed. The technical skills of a hydrologist/hydraulic engineer is needed to lead the hydrologic modeling effort and assure a physically based design. Two hydraulic engineers with hydrologic modeling expertise are needed to develop and maintain the various models. A data manager with a geographic, economic, or ecological background is needed to manage the GIS system. A program analyst would provide computer system support. Modern work stations are necessary for the large computing tasks. Compatibility with the SFWMD's and ENP's existing and future modeling is important. Five (5) SunSparc 10's or equivalent, server, and color plotter are required to support the hydrologic modeling and GIS.

U.S. Geological Survey

The USGS Hydrologic Modeling Work Plan covers improvement of algorithms and parameters for major flow pathways in hydrologic models, measurements to supply gaps in needed data for model calibration and validation, and the development of spatial data bases and digital maps to support modeling.

USGS hydrologic modeling objectives are to (1) review and evaluate the algorithms that comprise the existing regional model and perform error and sensitivity analyses, (2) improve parameters concerning aquifer characterization (permeability, etc.), evapotranspiration, vegetative resistance to flow, and land elevation, and (3) construct and test a framework of computer codes for integrating numerical models of hydrologic and hydrodynamic processes such as overland, channel, and groundwater flows and transport (also improve methods for simulating the nonlinear dynamics of fluid-driven mass and constituents in connected canal/wetland systems [develop a coupled mathematical/numerical model]), and (4) measure and model the groundwater flow from Water Conservation Area 3B under the protective levee.

Measurement efforts will cover surface freshwater discharge to the East Coast, surface and groundwater discharge to Florida Bay, and surface freshwater discharge to the southwest coast. Many of the canal and creek

flows to Florida Bay and the southwest coast are not presently measured. Stage data are recorded for the east coast canals, but calibrations to relate discharge to stage data are erroneous and need to be redone.

Data base development will involve the preparation and maintenance of a distributed spatial data library and the preparation of digital orthophoto maps that can provide improved topographic input to hydrologic models.

Everglades National Park

"Numerical Modeling Studies" is an ongoing project that focuses on the development and application of hydrologic models to improve our understanding of the principal processes operating in the Everglades. Existing models, particularly the SFWMM and the NSM, are being used to help evaluate proposed structural and operational changes in the canal system. Model output produced by simulating proposed alternative strategies are processed, evaluated, and documented specifically with regard to their effects on hydroperiods and hydropatterns in the natural areas of Everglades National Park. These interpretations are then used by ecologists to evaluate impacts on the ecosystem. In order to enhance the reliability of the current models, particularly in the wetlands, the Park's hydrologist and modeler are engaged in evaluation of the algorithms and data sets associated with the models. Several Park produced suggestions and work products have already enhanced the current models.

Future work products expected from the Park water resources staff related to the Restoration initiative and on-going projects: the experimental water delivery program, the Modified Water Deliveries project, and the C-111 GRR. A higher level of effort by the Park hydrology staff will be needed to evaluate impacts of alternative strategies on wetlands for the Restoration effort and to provide the support to improve wetland-related algorithms and data sets. Improved rainfall/runoff formulas developed by the Park's cooperators to return the wetlands to a more natural condition and revised operational schemes to improve freshwater deliveries to Florida Bay will require extensive evaluation before implementation. Wetland modeling will be heavily used in these analyses and will require additional support.

The additional work assignments will require additional support staff to provide the pre- and post-processing of the input and output data generated by the models. Two positions are needed to meet the requirements of the C&SF Restudy and the South Florida Ecosystem Restoration Initiative. Needed are a technical support person to provide the workstation software and a hardware support, and a database manager to provide application and interfacing support.

National Oceanic and Atmospheric Administration

The National Marine Fisheries Service and the National Ocean Survey of NOAA currently are participating in hydrologic model planning and evaluation activities in order to insure that modeling needs with respect to freshwater outflow to estuaries, particularly Florida Bay, will be addressed in future model upgrades and replacements and in data collection to support modeling. These needs are not adequately being addressed by existing models, although the Science Sub-group Report (Weaver et al. 1993) suggests a procedure for analyzing certain "freshwater outflow indicator" output of existing models for use in environmental assessment of estuarine impacts of proposed structural and operational changes in the C&SF Project. The suggested procedure uses outputs from the existing SFWMM and NSM. NOAA/NMFS proposes to work with other Federal agencies and the South Florida Water Management District to develop and implement analyses and environmental assessment procedures for simulation data that can be used as an index of freshwater flow to Florida Bay and Biscayne Bay. Results can be used develop operational guidelines and to evaluate alternative strategies proposed to improve estuarine conditions. NOAA/NMFS's participation in model development planning activities and the proposed analysis will increase the potential that the Restoration effort will improve conditions in estuaries. NOAA/NMFS's involvement in this effort and model planning and evaluation activities will help to interface hydrologic models with future hydrodynamic models for Florida Bay and Biscayne Bay. Technical support staff and travel funds are required for this initiative. No NOAA funds are available for this task.

South Florida Water Management District

SFWMD is developing a new South Florida Regional Simulation Model (SFRSM), which will be a completely redesigned version of the existing SFWMM with extensions to simulate the natural system (region without water management facilities). It will not be a modified or enhanced version of the existing codes of the SFWMM and NSM, but a completely new model designed to analyze future regional water management alternatives efficiently using the best available techniques, computer technology, and data. This new SFRSM will take advantage of recent advances in computer technology, in particular, GIS, Databases, and Object Oriented Model Development. It will use the more realistic, accurate, and efficient numerical algorithms that were not implemented during the original development of the SFWMM due to resource limitations and lack of data.

The development of the new SFRSM will be a 3-yr collaborative research project for a team consisting of SFWMD staff and two contractors. Several Federal and local agencies that are end users of the model (USGS, USACE, Everglades National Park, and Dade County) will be encouraged to participate in early planning workshops to define model specifications and will be kept abreast of developments from this project. Model development will be carried out in three phases: (1) analysis of the system, (2) model design, and (3) model development.

To establish and maintain needed in-house expertise in regional model development and application, SFWMD staff will direct and coordinate all model development activities and perform most of model development. Because of time constraints and the desire to acquire the state of the art technology, SFWMD will contract for determining functional requirements using the object-oriented methodology and developing user and database interfaces. Two contractors have been selected.

MODELING HYDRODYNAMIC PROCESSES

INTRODUCTION

Hydrodynamic models are needed to address the major ecological questions concerning Florida Bay. A hydrodynamic model is needed to simulate salinity patterns and circulation processes within the Bay as a function of freshwater inflow, local precipitation, wind, and regional circulation processes. Regional circulation models of the eastern Gulf of Mexico and the Florida Straits should be used to provide necessary support for a hydrodynamic model of Florida Bay. Some questions that the models must addressed are as follows:

- What are the patterns of salinity and circulation in Florida Bay in relation to freshwater inflow?
- How does water from Shark Slough affect salinity patterns, circulation, and nutrient dynamics in Florida Bay?
- What are the major factors influencing circulation in Florida Bay?
- What are the oceanic contributions of nutrients to Florida Bay relative to the terrestrial contributions?
- How are algal blooms in Florida Bay influenced by circulation?
- What is the turnover time of water in Florida Bay and how does it differ by region of the bay?
- How has the Overseas Highway affected the circulation of Florida Bay?

MAJOR ISSUES

The major issues that must be addressed in developing a capability to answer the above questions are as follows:

- Lack of a hydrodynamic model that can relate circulation and salinity in the bay to freshwater inflow.
- Lack of hydrographic data with which to create boundary conditions and obtain other parameters for a hydrodynamic model.
- Unknown influence of circulation patterns in adjacent waters.
- Lack of measurements of freshwater inflows to Florida Bay.
- Lack of models to adequately model freshwater inflows to Florida Bay as a function of rainfall.

BACKGROUND

A workshop sponsored by Everglades national Park and organized by the Florida Institute of Oceanography, in cooperation with NOAA, was held October 13-14, 1993. Much of the following material was derived from the workshop proceedings.

SCOPE

The scope of the hydrodynamic modeling program must of necessity extend beyond the boundaries of Florida Bay to the processes influencing conditions along the boundaries of the Bay.

OBJECTIVES

Objectives are to develop a system of circulation models to predict circulation, mixing, and salinity patterns in Florida Bay as a function of freshwater inflow and other variable factors. The system will consist of:

1. A 3-dimensional model for Florida Bay, quantified for operating in 2 dimensions until sufficient data to support 3-D runs can be obtained.

2. A regional numerical ocean circulation modeling system that can provide boundary conditions for the Florida Bay model.

3. A salt budget model for Florida Bay.

Another objective is to acquire sufficient data to run, first the 2-D version and then the 3-D version of the hydrodynamic model.

APPROACH

Ultimately a 3-dimensional hydrodynamic model will be capable of resolving the tidal, density driven, and wind driven components of the circulation of Florida Bay, and this will allow an adequate examination of the effect of freshwater inflow on Florida Bay salinity and circulation patterns to be made. The data with which to parameterize a 3-dimensional model are, however, lacking. Therefore, initial modeling efforts will focus on application of existing models using available information. Modeling activities will answer first order questions of mass balance and help determine the specific data required for higher resolution modeling.

Major data needs for the hydrodynamic models are:

- Boundary conditions along the western margin of the Bay and in the Keys channels.
- Elevation data for existing ENP continuous monitoring stations (surveyed in).
- Ground and surface water flows into the northern part of the Bay (both measured and provided by hydrologic models).
- Updated topography of Florida Bay.
- Precipitation data for the Bay (from Radar estimates).

Models of the offshore circulation will be used to provide the external forcing for the Florida Bay models. Existing models will be adapted for this use.

MODELING METEOROLOGIC PROCESSES

INTRODUCTION

Rainfall is the major source of freshwater to South Florida. During the rainy season (May-October), easterly waves, cold lows, depressions and other tropical weather disturbances contribute about 50% of the annual precipitation. The remainder of the wet season rainfall (roughly 1/3 of the annual total) is from daily thunderstorms associated with the convergence generated by sea breezes from the east and west coasts (Burpee and Lahiff 1979, Burpee 1984, Woodley et al. 1982). Dry season rainfall associated with frontal passages supplies <20% of the annual precipitation. Hence an understanding of tropical weather disturbances, coastal sea breezes, and their interactions are critical to modeling and predicting the behavior of the atmosphere over South Florida.

Soil moisture, vegetative cover, surface roughness, and albedo all influence the stability of the overlying atmosphere and help control the development of the sea breeze convergence zone and its resulting thunderstorm complexes. The natural system hydrologic model of Fennema et al. (1994) suggests that a considerably larger area of surface water existed in South Florida for more of the year in the predrainage system than occurs today. Furthermore, a comparison of satellite imagery of South Florida reveals that extensive areas that previously were vegetated are now covered with concrete or asphalt. It is important to quantify the changes in rainfall patterns that might have occurred due to these alterations.

Hydrodynamic models of Florida Bay are being developed to show how changes in freshwater inflow affect Bay salinity patterns and circulation. These models will depend heavily on estimates of freshwater inflow, direct precipitation over Florida Bay, and wind fields. Hydrologic models will be the major source of information on freshwater inflows to the Bay. Meteorologic models, by contributing more accurate precipitation data to hydrologic models and by providing precipitation and wind stress fields for Florida Bay, can insure better performance from the hydrodynamic models.

MAJOR ISSUES/PROBLEMS

- Rainfall over south Florida is highly variable in both space and time, causing errors in estimates of total rainfall from spot measurements. These errors can affect the accuracy of hydrologic models and their ability to predict stream flows. High resolution quantitative precipitation predictions for south Florida are not currently available.

- Changes in land surface influence rainfall. The area of moist surface or surface water influences evapotranspiration, which feeds convective rainfall. The replacement of forested surfaces with paved surfaces affects albedo and the vertical temperature gradient. There have been many changes of this type in South Florida in the past century, suggesting that rainfall could have changed as a result.

- Surface wind stress is a dominant force determining circulation in Florida Bay, and surface wind predictions are needed for input to hydrodynamic models of Florida Bay.

- Direct precipitation is a major source of freshwater to Florida Bay, and is poorly measured. High resolution spatial rainfall predictions for Florida Bay are not currently available.

- Improved accuracy and resolution of hydrologic models is important to the restoration effort and is also important to water managers in handling stormwater runoff following major rainfall events.

- Evaporation is another important influence on salinity patterns and circulation in Florida Bay, but information on evaporation is lacking.

- A regional meteorological model would be useful in improving rainfall, runoff, wind stress, and evaporation estimates, but does not currently exist for South Florida.

BACKGROUND

At present, no mesoscale atmospheric model is in place to specifically address these issues. The numerical models that are currently available are run operationally at the National Meteorological Center (NMC) and have domains that cover the entire earth (global models) or most of North America (regional models). Because of this large area of responsibility, the horizontal resolution of the NMC models is too coarse (about 100 km for the global models and 50 km for the regional models) to adequately represent the local atmospheric circulation in the South Florida region.

SCOPE

The immediate area of interest is south Florida and Florida Bay. A model domain will necessarily cover between 5-10 degrees latitude square; it will be bounded on the north by Tampa and Melbourne and on the south by the Cuban coast.

OBJECTIVES

Objectives are to develop a regional model that is capable of the following: (1) predicting wind stress over south Florida and Florida Bay and adjacent marine areas, (2) predicting precipitation over south Florida and Florida Bay as a function of regional weather patterns and local land surface conditions, and (3) estimating evaporation over Florida Bay.

APPROACH

Adaptation of an appropriate existing model is the most effective way to satisfy the need for a regional meteorologic model of South Florida. Needed is a high resolution (1-10 km grid), non-hydrostatic model suited to simulating thunderstorm complexes that form due to the convergence of sea breezes from the east and west Florida coasts. With proper boundary conditions, this model should be suitable for prediction of heavy rain episodes associated with tropical disturbances and fronts. The model should be capable of supplying boundary conditions to ocean and bay circulation models and hydrologic models. The model should be able to accept initial input boundary conditions from the hydrologic model.

A model that appears to satisfy these needs is the Advanced Regional Prediction System (ARPS) model that was developed with NSF support at the University of Oklahoma's Center for Analysis and Prediction (Droegemeier, et al. 1991). Additional advantages of this model are explicit cloud microphysics (critical for resolving individual thunderstorm complexes), an adaptive grid in which grid points are dynamically redistributed for increased resolution in high gradient regions, and ease of portability among different computer architectures. The surface evaporation and radiation budgets of the model are highly dependent on landuse, vegetation and soil specifications which help determine the soil moisture, surface albedo, roughness length, surface heat capacity, the fraction of a grid cell covered by vegetation, the evapotranspiration and the surface temperature. Since several of these quantities are also used in hydrological models, interaction with scientists at SFWMD the National Park Service, and other agencies will be an important step in adapting the model to south Florida.

NEXRAD WSR-88D radars will be operational near the four corners of the model domain at Miami, Tampa, Melbourne and eventually Key West. NEXRAD can be used to help calibrate and validate the model.

A future design feature of selected model is an automatically generated adjoint version for 4-D assimilation of asynoptic NEXRAD radar data and mesonet observations. This capability will be especially useful in predicting, after their initial formation, the subsequent development of thunderstorm complexes due to outflow interactions and mergers.

The adaptation of the ARPS model to the South Florida environment is a multi-year project that has been initiated by the Hurricane Research Division of NOAA's Atlantic Oceanographic and Meteorological Laboratory in cooperation with the Miami National Weather Service Forecast Office and the South Florida Water Management District. The first year's work will proceed in the following steps:

- Download the version 4.1 of the ARPS model code and begin to set up model parameters appropriate for the South Florida simulations.

- Make arrangements for obtaining 300 h of CPU time and remote supercomputer access on the University of Alaska Cray-2 for testing the model with high resolution.

- Make necessary software adaptions for running the model on existing HP-755 workstations, supplementing storage and memory capabilities as required.

- Perform an inventory of available surface observations (including anemometers and rain gages) to determine the optimal method of constructing fields for model evaluation.

- Investigate options available for high resolution local databases of terrain, coastline bitmask, land use, soil type, and vegetative index required to adapt the model to south Florida.

- Organize an informal workshop with local circulation and hydrology modelers and operational meteorologists from the National Weather Service and SFWMD to encourage cooperation and interaction, discuss overlapping boundary condition interests, grid geometries, simulation experiments and verification data and address potential cross-discipline use of the ARPS model.

- Obtain and develop software for presenting and evaluating model results. Perform model tests using idealized homogeneous sounding background state initial conditions. Arrange for acquisition of larger-scale three-dimensional initial conditions from the operational National Meteorological Center Eta model for later real data simulations.

Continuing into subsequent years, research steps are as follows:

- Obtain data for model test cases, including WSR-57 or WSR-88D radar data for verification. Initialize the model with observed data and evaluate the ability to predict the organization of precipitation by comparison with radar data and rain gage data where available.

- Perform a natural system sensitivity test to estimate the impact of changing land use and soil conditions on the typical summer-time sea breeze thunderstorm development cycle and subsequent rainfall distribution.

- If appropriate, conduct a field experiment using the sophisticated suite of atmospheric and oceanographic sensing equipment aboard the NOAA P3 aircraft to better define initial conditions for a real time model test and document thunderstorm evolution.

- Evaluate the prediction of surface wind fields by comparison with all available wind observations. Develop and apply techniques (e.g. DeMaria, et al., 1992, Powell and Houston, 1993) for generating detailed surface wind analyses for input into ocean and bay circulation models. Investigate the possibility of using WSR-88D wind and reflectivity data to initialize and verify the model.

The eventual goal of this work is to provide the atmospheric component of a comprehensive coupled hydrologic-hydrodynamic-meteorologic model containing the Everglades, Florida Keys, Florida Bay, Biscayne Bay and portions of the Atlantic and Gulf of Mexico basins.

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MODELING ECOLOGIC PROCESSES

INTRODUCTION

Ecological models are an essential component of the South Florida Ecosystem Restoration Program. Models that relate species, populations, communities, and landscapes to the simulation outputs of hydrologic models are the only objective way to evaluate alternative water management strategies for their influence on landscapes, plant communities, and wildlife. Ecological models are needed in the restoration effort for many reasons, but the most important is to build understanding about the connections between hydrologic conditions and ecosystem structure and function. The South Florida Ecosystem Restoration approach is based on the reasonable premise that hydrologic restoration is the foundation of ecological restoration. Models are essential to determine why this is so, identify key characteristics of the predrainage hydrologic system that maintained predrainage resource abundances, and quantify the relationships between hydrologic variables and indicators of ecosystem health. These models must demonstrate how certain key features of the predrainage Everglades--large spatial extent, spatial heterogeneity, sheet flow, and dynamic storage--supported a healthy ecosystem-- a system resilient to perturbations and supportive of an abundant and diverse vegetation and wildlife. A quantitative explanation of the connections between hydrologic function and ecosystem health is needed to strengthen scientific understanding about why these system attributes must be reinstated and to communicate this understanding to managers and the public.

Models are critical to the adaptive management approach that will be employed in the restoration effort. The most useful models for South Florida Ecosystem Restoration will be those that will both help understand the connection between ecosystem health and hydrologic function and can be used to assess the effect of proposed management alternatives. For use in assessment, models must be able to simulate selected ecological success measures.

Assessment needs should be given the highest priority in model development. Ecological assessment models are needed for all phases of the redesign of the Central and Southern Florida Project, from the initial justification (reconnaissance) phase through feasibility, field testing, implementation, and monitoring. While simple assessment models, including both diagrams and line graphs, if based on scientifically credible concepts, may be useful in some applications, the immediate and longterm need is for models that embody the general structure of the system and exhibit ecosystem function. Ecological models that can respond to the output of spatially-explicit hydrologic and landscape models and integrate the support functions of a spatially heterogeneous system are essential.

Models that can demonstrate why and how the natural hydrologic system supported a greater abundance and diversity of fish and wildlife, cleaner water, and other indicators of ecosystem health will be the most reliable models for testing the benefits of alternative water management structures and operations. Such models may help managers distinguish between changes occurring due to the change in water management strategy and changes occurring for other reasons.

Population trends, plant community succession, and various ecological processes simulated under present and predrainage conditions with the same time series of rainfall can be used to make comparisons that will show which aspects of the altered hydrologic regime have had the major affects on the ecosystem and the natural relationship of spatial and temporal patterns of hydrologic conditions with species, communities, and landscapes characteristic of South Florida. The predrainage simulations will provide an ecologically supportable, objectively determined, and relatively unbiased target for restoration efforts.

The predrainage natural system is a good restoration target because we know it functioned well in supporting the landscape patterns, clean and abundant water supplies, and large populations of wading birds, game fish, and other wildlife we want to regain. It is an unbiased target because it does not favor one species or

community over another, but rather the ecosystem as a whole. Because of irreversible changes that have occurred with the expansion of the modern human population, we cannot expect to totally regain the original species richness and wildlife abundance of the area. However, having a target based on predrainage conditions, as best they can be defined, will insure that the restoration effort leads to change in the right direction. Simulations from "natural system" executions of hydrologic and ecologic models (Fennema 1992, Fennema et al. 1994) will provide standards against which to test alternative management actions and to measure success, once actions are implemented.

Critical to the development and application of assessment models are (1) an assessment protocol that defines how the models will be applied and (2) a support framework for model development and application. An assessment protocol can help focus modeling, monitoring, and research toward simulating, monitoring, and understanding selected ecological assessment indicators. Modelers should be included in the coordinated process of developing the assessment protocol.

MAJOR ISSUES

- Ecological models are critical to application of the adaptive management methodology adopted by The Working Group, and an adequately and continuously funded, concerted model development program is needed.

- Landscape models are needed that simulate vegetation succession as a function of the hydrologic regime and aperiodic events, incorporate land shaping processes such as soil accretion and soil subsidence, can interact with hydrologic models to affect hydrologic processes, and can provide the explicit spatial framework necessary for models of species and communities that are influenced by landscape patterns. Landscape models in progress need to be reoriented to meet these needs.

- Model development activities should involve South Florida experts concerning the species or community being modeled and should involve scientific oversight that helps focus the modeling effort on implementation for ecological assessment.

- The success criteria recommended in Science Sub-Group (1993) need to be refined into a set of appropriate and workable ecological assessment indicators for both immediate and longterm applications.

- An ecological assessment protocol is needed to ensure that monitoring and modeling efforts are focused on providing the ecological assessment indicators.

- A monitoring program that focuses on the selected ecological assessment measures needs to be designed and supported.

- Model development should be supported by--and incorporated with--research to supply critical information needs.

- Information is very limited for certain species and communities (i.e., apple snail, periphyton community, mangrove fish community) that, otherwise, would make valuable indicators because they are so important in the system. The ecology of important potential indicators should be major research topics.

BACKGROUND

The field of ecological modeling, although less well developed than that of physical modeling, has made significant progress. Even with the limited funding so far allotted to ecological modeling for the South Florida restoration effort, several models are under development, and some are near the application stage (DeAngelis et al.

unpublished report, Fleming et al. submitted, Fleming et al. in press, Fleming et al. in press, Fleming et al. in press, Fleming et al. in press, Fleming et al. in review, Fong and Harwell in press, Wolff 1993, Wu et al. unpublished report, Wu et al. unpublished report). Modeling systems that can integrate the ecological system across scales appear to be the most useful, because restoration will require an ability to understand and predict interrelated processes operating from microhabitat to landscape levels. Species, community, and landscape level models are needed to address the relevant questions. For instance, understanding the entry of mercury into the ecosystem, its transformations, and how it accumulates in animals at all stages of the food chain is an important question that requires models capable of integrating across several scales.

Species-level models are needed to determine the critical interactions of various plant and animal species and the influence of landscape and hydrologic patterns. Certain species, by their recruitment or behavior, act as sensitive indicators of ecosystem function. For instance, Wood Storks and Snail Kites, because of their wide foraging areas and specific foraging requirements, reflect ecosystem functioning at the landscape level in their recruitment. Other species are of interest because of their threatened status. Models are needed to test the effect of water management options on such species.

Community-level models should simulate ecosystem processes operating in periphyton communities in the freshwater Everglades, nuisance algal blooms in Florida Bay, freshwater macrophyte communities experiencing a change in species dominance, and fish communities supporting colonial nesting wading birds. The need to control the spread of invasive non-native species into native plant communities is another concern that should be addressed by community-level modeling.

Florida laws suggest other community-level modeling needs. The water quality standard states that discharges into protected waters should not cause an "imbalance" in natural plant and animal communities. But what constitutes imbalance? Models are needed to address the concept of ecological balance in a descriptive and quantifiable sense. As another example, the South Florida Water Management District (SFWMD) is required by state law to determine minimum flows for freshwater wetlands and estuaries. Estuarine models capable of relating freshwater flow to ecosystem productivity and natural resource abundance are needed to help define minimum flows.

The landscape not only is influenced by the hydrologic regime but also influences this regime by affecting flow rates and defining flow paths. Land contours are influenced by vegetation growth and the hydrologic regime through their effects on soil accretion and subsidence and battery formation. Patterns of land and water influence the reproductive activities of wading birds, deer, and other animals. Issues related to these topics require landscape models for use in interaction with other models.

Some major questions of restoration can only be answered with landscape models, applied in concert with trend and gradient analyses and paleoecological investigations. Models and paleoecological results can be mutually supportive in terms of describing prior conditions. Landscape modeling is dependent upon hydrologic modeling and needs to be fully integrated with hydrologic modeling studies. Landscape models, in combination with hydrologic models, are needed to address questions concerning ecosystem and wildlife responses to restoration actions.

One important landscape model that is envisioned is spatially explicit (GIS-based) and should be used not only to examine present landscape structure in relation to hydrologic forces but also to recreate the predrainage landscape. The approach should be to start with the basement structure and use the natural hydrologic model, in conjunction with the landscape model, to accumulate soil and create a landscape as a function of the basement structure, the hydrologic conditions, and forcing events, including fire, rainfall extremes, sealevel rise, and climate change. The consequences of various scenarios of control structure configurations and operation strategies could be shown in terms of the mix of ecosystems and the landscape mosaics that result.

Surficial topography and landscape result from the forces acting on the basement substrate. They arise from the accumulation of soil and peat. To predict the outcome of restoration actions, soil accretion and subsidence

should be modeled as functions of water depths, hydroperiods, fire regimes, vegetation, and other influencing factors. Estimates of rates of soil accumulation and landscape building are needed to support this model usage.

One of the most important uses of this landscape model should be to determine how changes in landscape influence the hydrologic regime, including flow rates, hydroperiods, and hydropatterns. While it is known that vegetation patterns influence water flow, the effect of landscape change on water patterns in this system has not been examined.

A landscape model might be verified by imposing the C&SF Project on the predrainage landscape and simulating the landscape change over time; the resulting landscape can then be compared to the present landscape.

CURRENT MODELING PROGRAMS

Many activities to support the South Florida restoration effort have already been started by various agencies. Specific funding will have to be delegated to most of these programs in the future in order for them to continue.

National Biological Survey

ATLSS

The National Biological Survey in Miami, in cooperation with Everglades National Park, Oak Ridge National Laboratory, Chesapeake Biological Laboratory, and Florida International University, is developing a modeling system called "Across-Trophic-Level System Simulation" (ATLSS) for application to South Florida restoration issues. As envisioned by its developers, ATLSS consists of:

1. An integrated system of spatially explicit simulation models of the major trophic groups that will be coupled through a spatially explicit landscape structure that accepts information on elevation and vegetation as well as the outputs of hydrologic and landscape simulation models.

2. Trophic flow-network ecosystem analysis to identify the primary ecological components in each system, exchanges of energy and material among these components, and pathways of recycling for carbon, phosphorus, and nitrogen.

3. Coupling of the across-trophic level simulation modeling system with flow network analysis models to evaluate the outputs of the simulation models and provide a quantitative view of changes in system trophic structure and function and resultant changes in stocks and major nutrient cycles under various scenarios of water management strategy or other anthropogenic controls.

Modeling of trophic groups will take three approaches: lower trophic level organisms will be represented with process oriented models, intermediate trophic level organisms will be represented with age and size structured aggregated population models, and higher order vertebrates such as wading birds will be represented with individual-based models. These trophic level models will be coupled as described in (1) above.

The modeling work is fully integrated with research currently being conducted in the Everglades/Big Cypress region and will allow research results to be interpreted at the whole system level. Progress has been made in individual-based models for Wood Storks, Florida Panthers, Alligators, and Everglades White-tailed Deer. Progress has been made on aggregated models for the freshwater fish community, and a process oriented model for the periphyton community.

The modeling system will provide a rigorous integrative approach for testing hypotheses related to chronic stresses on the system and their interactions with major pulse disturbances such as hurricanes. Such research is necessary to formulate a system-wide restoration plan within the context of regional water management.

GAP

Biodiversity modeling at the landscape scale is the South Florida Project planned at the National Biological Survey Florida Cooperative fish and Wildlife Research Unit in Gainesville. Following is a description by its participants.

The South Florida Project is part of an overall state project that is Florida's Gap Analysis program. GAP Analysis a proactive approach to protecting biological diversity using surrogates such as land cover and species richness to assess the conservation value of large geographic areas in a quick and cost-effective manner. It is the first step in a nationwide program to assess how much existing biological diversity falls within lands that are managed in some way for natural resource protection. The program's approach is to map land cover and model potential vertebrate habitat based on land cover and other spatial data. By overlaying modeled habitats, species richness can be spatially determined and compared to areas set aside for conservation. Areas of high species richness that fall outside of conservation area boundaries are referred to as "gaps" in protection. The Florida Biological Diversity Project in south Florida will provide (1) a base for existing land cover and potential habitat richness and (2) a quick, cost-effective model for estimating change in potential habitat richness as a result of restoration alternatives.

In preparation for this project, Landsat thematic mapper imagery have been obtained for the entire state. Image classification and existing spatial information on topics such as soils will be used to map habitat. Land use classification will be based on the Florida Natural Areas Inventory, the Florida heritage program of the Nature Conservancy. Distribution and habitat association data are being compiled from museum records, literature, and consultation with experts for all species of terrestrial mammals, breeding birds, and butterflies in the State. Distribution data are used to restrict the range. Within that range, knowledge of wildlife species habitat preferences is used to build a model of potential habitat. The models may use land cover type, minimum viable areas, proximity to other necessary land covers (e.g., for some birds, nesting requires a land cover type within a certain distance of another land cover type where the bird forages), and other spatial metrics.

A grid coverage with multiple attributes, one for each modelled species, will be used to store the results of the potential habitat models. Several coverages with differently sized grids will be created, and each species will be associated with the coverages that best reflect the scale of its response to its environment (a pig frog responds to a smaller immediate environment than a Florida panther). The final layer of information is a coverage of the boundaries of lands set aside for conservation. This includes federal and state parks, refuges, and wildlife areas, water management district lands, county and municipal park lands maintained as natural areas, and lands owned by Audubon, the Nature Conservancy, and other conservation groups. When this coverage is compared to the species richness products, areas of high biological diversity which are not within protected areas can readily be identified.

Funding shortfalls exist where application of GAP to the South Florida Ecosystem Restoration are concerned.

1. Ground truthing is critical to creating a quality land cover product, and accuracy assessment is the necessary last task in land cover classification. Both tasks are costly and time-consuming. A botany technician is needed who can devote large portions of time to on-site land cover identification. Helicopter surveys are the only practical way to perform accuracy assessments covering all the community types in South Florida with adequate samples for statistical significance.

2. Current equipment is not adequate to handle the thousands of megabytes of data being generated by Gap Analysis in South Florida. An additional 15 to 20 gigabytes of hard drive storage, a jutebox optical drive, and an additional workstation for data analysis are being sought.

3. The Marine Gap Analysis is currently unfunded. Much of the required data is currently being collected under other programs, but some basic supplies, technical assistance, and ground-truthing data acquisition need support.

NOAA-National Marine Fisheries Service

NOAA/NMFS is also planning modeling activities in relation to the restoration effort. Following is an NMFS description of these activities.

Statistical and simulation population models that relate pink shrimp to juvenile estuarine habitat and environmental variables such as freshwater inflow are funded for FY-94. Resource surveys, physiological trials, and genetic analyses of pink shrimp will support the modeling. The study will characterize the within-year cohorts in the fishery and link them to specific nursery grounds in Florida Bay and nearby estuaries. Pink shrimp catch rates suggest a longterm stock decline, with an increasing rate of decline in the past decade. The study is designed to gain understanding on how natural variability and anthropogenic manipulation of freshwater inflow affect pink shrimp recruitment.

The pink shrimp is viewed as a good indicator of ecological health of Florida Bay. A relatively long time series of consistent catch and effort data from the Tortugas pink shrimp fishery is available for analysis. Previous statistical analyses indicate that pink shrimp are sensitive to freshwater inflow. Furthermore, pink shrimp are a principal prey item of many important game fish species in Florida Bay and are an intermediate trophic level consumer in both the detrital and the algal food chains.

Beginning in FY-95, field activities will quantify the use of seagrass and mangrove habitats within Florida Bay to explore the linkage between seagrass and mangrove habitats. The seagrass die-off in the Bay has caused changes in fisheries habitats and species composition. Juveniles of many species are having to use alternative habitats. A NMFS and Florida DEP cooperative effort will develop an ecological model incorporating linkages between habitats in order to gain an understanding of pre- and post-die-off community composition. This information will be used to predict changes in utilization with restoration.

A primary producer model that simulates the feedback between water quality and ecosystem structure, as influenced by nutrient loading, is a proposed activity for FY-95 and beyond. Seagrass beds not only are influenced by nutrient availability, but also influence nutrient concentrations. The model would explore the interactions of seagrass beds with nutrient cycling.

NMFS modeling funds for FY-95, FY-96 and beyond depend on NOAA allocations. Tentatively planned, beginning in FY-96, is a bay-wide spatial modeling study that examines distributions and densities of living resources in relation to salinity patterns superimposed over bottom and shoreline habitat. The project will examine how the area of overlap of favorable salinities with favorable bottom features for juveniles of various species changes with alteration in freshwater inflow. It will predict Bay "production capacity" as a function of overlap area. This modeling activity will integrate and interpret in an ecological context the NOAA/NMFS C-CAP map of bottom habitat and salinity maps resulting from a proposed cooperative study involving NESDIS, NMFS, and AOML and using an airborne sensor.

NOAA - NESDIS//NMFS/OAR

In a project dependent on NOAA FY-95 and FY-96 funding allocations, NESDIS, NMFS, and OAR propose to perform synoptic mapping of Florida Bay with a light weight, GPS logged, airborne salinity sensor. Determining the relationship between freshwater discharge and salinity patterns is critical to the overall Florida Bay

restoration effort. Salinity patterns in Florida Bay are complex because of the Bay's basin-bank topography, wind effects on water movement, and the number of locations of freshwater input. Because of the Bay's large size and complexity, the most practical and accurate way to map salinities is with the airborne sensor, which is a specialized microwave radiometer designed for this use. Groundtruthing will be used initially to insure the accuracy of the salinity instrument in Bay waters. The salinity mapping effort will produce paper and digital maps for use in NMFS's productive capacity study. The data can be used to calibrate and validate hydrodynamic models of the Bay that are also planned. First year activities will be a pilot study to determine the logistics of mapping Florida Bay. Routine mapping of the Bay with a biweekly or monthly periodicity may follow, subject to funding.

South Florida Water Management District

The Everglades Landscape Model (ELM) under development at the South Florida Water Management District is another promising modeling concept that should be nurtured for its potential use in ecological assessment related to the restoration effort. Coordination of the development of the ELMS model with other modeling and research activities is needed. The ELMS model is a grid-based biomass model that incorporates its own hydrologic model. Operating at appropriate timescales, it could simulate ecosystem evolution and geomorphologic development, with vegetation succession and hydrologic regime interacting.

Environmental Protection Agency

The Athens Environmental Research Laboratory (AERL) has begun an investigation to understand the environmental factors that influence the rates of microbial mercury methylation and demethylation, to identify sources and transport patterns of mercury consistent with current conditions and historic changes in the Everglades, and to evaluate mitigation and control strategies. The first phase of work is designed to expand understanding of the biogeochemistry of mercury to a stage at which robust predictive models can be constructed. The first goal is to identify the role of microbial activities in the fate, transport, and biological uptake of mercury and to understand the full gamut of environmental constraints on these processes, while taking into account unique attributes of the Everglades and the anthropogenic stresses to which it has been subjected. The second goal is to clarify the role of inorganic geochemical processes in the mobilization and transport of mercury, including those processes governing its availability to bacterial methylation and demethylation and its bioaccumulation in higher organisms. Model development will be coordinated with experiments and acquisition of data and field samples from the EPA Region IV REMAP (EPA Regional Environmental Monitoring and Assessment Program) sampling effort.

OBJECTIVES

- To formulate a protocol for applying models in environmental assessment
- To establish an institutional framework for supporting the development and continuing upgrading and application of models.
- To build a suite of models to address strategic questions that (1) relate to the restoration objectives and the adaptive management process and (2) simulate restoration assessment indicators. These models are to be both assessment tools and integral components of research efforts to support restoration management. These will be systems of linkable models that can simulate processes operating at several scales as functions of hydrologic conditions and other driving forces and as affected by major stresses such as droughts, floods, hurricanes, fire, and freezes. The models will embody current understanding of the system and be designed to accept the simulated output of hydrologic or hydrodynamic models directly or through other models. The models will assist in evaluating water management alternatives for their potential to improve ecosystem health. Model results will be testable to allow the models to be improved as part of the adaptive assessment process.

- To integrate modeling with development of a monitoring plan and research plans for special studies.

RECOMMENDED APPROACH

Model Development

Ecological model development should start at the beginning of the restoration effort, and research and monitoring should be fully integrated with the modeling. Only the development and application of ecological models, even with cursory data, can reveal the type of information that is needed from hydrologic and hydrodynamic models and demonstrate why it is necessary.

Restoration requires a historical representation. Quantitative descriptions of the hydrology and ecology of the predrainage system are lacking, although paleoecological research may someday provide some information on this topic. Meanwhile, the best guide for understanding the ecological ramifications of the changes in spatial extent and hydrologic conditions that have occurred from predrainage days to present will be spatially explicit "natural system" hydrologic models supporting a system of ecological simulation models that operate at several scales and are spatially explicit at the landscape level.

Natural system hydrologic models are versions of water management models in which the control structures have been removed and the topography restored to approximate the predrainage system. Spatially explicit hydrologic models, rather than "pot" models, are necessary because hydroperiod (duration of continuous water coverage), and hydropattern (where and when the water coverage occurs) are thought to affect vegetation coverage and the support value of wetlands for wildlife. Ecological modelers should use the output of natural system hydrologic models and support the continued upgrading, maintenance, and application of these models.

Many powerful and promising modeling concepts are contained in ATLSS, as described in a previous section and presented at a June, 1994, workshop sponsored by the Science Sub-Group. These concepts should be nurtured and encouraged with a greater level of funding and other support as part of the restoration effort. The modelers should receive guidance to ensure the models will simulate selected assessment indicators that are needed in the restoration process. Modelers should be helped to communicate more broadly with local authorities on the species and communities being modeled so as to ensure incorporation of the best available information into each model and widespread acceptance of the model by the scientific community. Properly directed and given adequate development funding, these models can be particularly useful for evaluating alternative management options and measuring restoration progress.

The NBS-GAP initiative described in the previous section is another approach that appears valuable to the restoration effort. GAP looks at biodiversity, protected species, and exotic invasions from a habitat perspective and provides a multispecies approach to optimizing native biodiversity, recovering threatened and endangered species, and controlling invasive non-indigenous species. GAP addresses many needs that can be inferred from the Sub-region presentations. GAP is a cost-effective means of region-wide analysis because it is based on remote sensing and computerized habitat classification and mapping.

A vegetative landscape model is needed that will be responsive to the dynamics of hydropattern and water quality over time and space. To address the major relevant questions, this model must be responsive to conditions that vary on seasonal, annual, and decadal time frames and involve changes in water management, climatic change, and events ranging from fire to rainfall extremes, freezes, and hurricanes. Essentially, what is needed is a model that will simulate landscape development, including vegetation succession, soil formation and dissolution, and change in elevations. Such a model is needed for many uses. It will be most effective if used interactively with spatially explicit hydrologic models where it would provide a dynamic landscape that influences water flow and surface water patterns.

The complementary projects being carried out at the South Florida Water Management District (ELM) and in a cooperative project by ENP/NBS/ORNL (ATLSS) can be considered a landscape studies program already underway. The program needs further support and some reorientation to meet the needs of the restoration effort. ELM, because it is spatially explicit, could be useful for simulating soil building processes, land recontouring, the formation of tree islands, sloughs, sawgrass stands, batteries, etc., and the effect of vegetation patterns on water flow, hydroperiods, and hydropatterns. The ATLSS landscape model will be most useful for understanding animal responses to the current landscape and landscapes arising from various restoration alternatives.

ELM, because it is biomass based and incorporates its own hydrologic system, could be the basis of the landscape model needed to generate landscape development in interaction with hydrologic regime, if model development were reoriented to keep track of soil building and depletion and to operate over near-geologic time scales. To be most useful to the restoration project, this model also must be expanded beyond the Water Conservation Areas and Everglades National Park. ELM should be networked or coupled with species assessment models ranging from habitat-related statistical models to individually-based species models. ELM, at its present resolution, will not capture the structural and process detail required to adequately evaluate all the important responses of the system to restoration. Therefore, subgridscale models within ELM should be developed at finer resolutions.

Further development of both landscape models should be integrated with the development of a restoration assessment protocol. Some guidance, as well as communication between modelers, should insure that the models are serving complementary needs.

In addition to landscape models, trend and gradient analyses and retrospective paleoecological studies should be a part of a landscape studies program. These techniques are required to generate essential information, which can then be used most advantageously through incorporation into landscape modeling.

Seascape models that provide spatially explicit views of estuaries also are needed in the restoration process to show how salinity patterns, as established by freshwater inflow, overlap with habitat features important to estuarine dependent species. Initially, attention should focus on Florida Bay. A model should be developed that will include bottom topography and the overseas highway and will integrate spatial information on salinity, circulation patterns, and nutrients. Hydrodynamic models that are planned should be designed to provide salinity to this model.

Ecosystem models must be designed to accept the output of hydrologic and landscape models and interpret these outputs in an ecosystem context. The promising ecological modeling systems already underway for use in South Florida should be fully supported and expanded in their application. Other modeling approaches should be encouraged, particularly to meet modeling needs that will not otherwise be met. The full range of potentially useful models should be considered in the context of the suite of capabilities that are needed. Models or modeling systems that can integrate the ecological system across scales appear the most useful, but the door should not be closed to other modeling approaches because modeling science, like the biological world, is evolving, and diversity provides the basis for successful adaptation.

Conceptual models have a role in the restoration effort. These models, which are composed simply of diagrams and descriptions, are a good way to integrate and communicate information and ideas. They are good organizing tools at the study beginnings and can provide the initial design basis for simulation models.

The right questions must be asked in order that models are developed that will allow models to provide meaningful information for decision making. How the question is framed may make a difference in whether it can be answered and, if answered, translated into effective management. In the appendix to this section are some representative questions that relate to system-wide objectives and the type of model that should be applied to addressing these questions.

Ecological Assessment Indicators

Those species and communities that play especially important roles in ecosystem function would be appropriate subjects for models that simulate ecological assessment measures. Subjects should be chosen that are thought to be sensitive to the types of changes being made. 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 having different responses to hydrologic regime. The American alligator might be another complementary addition to this selected group. Species that are indicators of region-wide ecosystem function would be particularly useful. The Wood Stork and other wading bird species are examples of this type because their feeding range is large and, by their choice of colony sites and in their reproductive success, they integrate information on secondary productivity and hydropatterns across broad areas. Pink shrimp, because they are a major prey of many fish species, represent the overall productivity of the estuarine ecosystem with their recruitment.

Initially, ecological assessment measures should be based on those species and communities to which considerable research attention has been given in the past so that both time series of data and an intellectual basis for model design are available. But other key species or communities should be identified for new research that will make it possible to measure restoration success by their responses. For instance, the apple snail is the critical prey of several species, yet little is known about its population biology and ecology. Filling this deficiency is an important need.

Assessment Protocol and Institutional Framework

The design of an assessment protocol should be done in concert with the development of models to insure that a workable and effective assessment procedure evolves. The assessment protocol should take advantage of models under development that have already demonstrated some promise. Further model development should take place interactively with protocol development.

An institutional framework to support ecological modeling is essential to the restoration effort because models are critical to the application of adaptive management methodology. Models have to be developed, refined, and maintained; therefore, models need continuous funding and a home.

As a beginning, the Science Sub-Group or its technical modeling team should formulate a plan that contains a suggested assessment protocol and institutional framework. The plan should identify core models and a workable set of measurable ecological indicators. To be useful, models must simulate these indicators or data from which they can be derived. The protocol design should take into consideration the information that can be generated by the models presently under development.

SUMMARY OF RECOMMENDED APPROACH

- **Design integrated modeling systems in which ecosystem models must accept the output of hydrologic and landscape models and interpret these outputs in an ecosystem context.**

The promising ecological modeling systems already underway for use in South Florida should be fully supported and expanded in their application.

- **Encourage and nurture the promising modeling concepts of ATLSS by providing continuous funding at an increased level, guidance to ensure the models will simulate ecological assessment measures, or indicators, and access of modelers to a wider group of authorities on South Florida ecology.**

ATLSS was described in a previous section and was presented at a June, 1994, workshop sponsored by the Science Sub-Group. Because of their ability to respond to hydropatterns and a heterogeneous landscape, these models are particularly suited for use in the South Florida Ecosystem restoration effort. Properly directed and given

adequate development funding, models developed within ATLSS can be extremely useful for evaluating alternative management options and measuring restoration progress.

- **Support the Florida GAP initiative to help it meet objectives of the South Florida restoration effort. Fill the "gaps" in GAP funding.**

The NBS-GAP initiative described in the previous section is another approach that has many values to the Restoration Effort. GAP looks at biodiversity, protected species, and exotic invasions from a habitat perspective and provides a multispecies approach to optimizing native biodiversity, recovering threatened and endangered species, and controlling invasive non-indigenous species. GAP addresses many needs implied by sub-region presentations. GAP is a cost-effective means of region-wide analysis because it is based on remote sensing and computerized habitat classification and mapping.

- **Support the independent landscape modeling initiatives started by the SFWMD and NBS/ENP/ORNL and give the modelers more direction to enhance the usefulness of the models for ecosystem restoration.**

A vegetative landscape modeling capability is needed that will be responsive to the dynamics of hydropattern and water quality over time and space. Model responsiveness is needed to conditions that vary on seasonal, annual, and decadinal time frames and involve changes in water management, climatic change, and events including fire, rainfall extremes, freezes, and hurricanes. Models should simulate landscape development, including vegetation succession, soil formation and dissolution, and change in elevations. This capability will fill many needs. Landscape models will be most effective if used interactively with spatially explicit hydrologic models, providing a dynamic landscape that influences water flow and surface water patterns.

- **Integrate landscape model development with development of a restoration assessment protocol. Some guidance, as well as communication between modelers, should insure that the models serve complementary needs.**

ELM, because it is spatially explicit, could be useful for simulating soil building processes, land recontouring, the formation of tree islands, sloughs, sawgrass stands, batteries, etc., and the effect of vegetation patterns on water flow, hydroperiods, and hydropatterns. The ATLSS landscape model will be most useful for understanding animal responses to the current landscape and landscapes arising from alternative water management strategies proposed to support ecosystem restoration.

- **Support trend and gradient analyses and retrospective paleoecological studies as part of a landscape studies program that includes landscape models.**

These techniques are required to generate essential information that can be used most advantageously through incorporation into landscape models.

- **Develop models that provide spatially explicit views of estuaries to determine how salinity patterns, as established by freshwater inflow, overlap with habitat features important to estuarine dependent species.**

Initially, attention should be focused on Florida Bay. The model should include bottom topography and the overseas highway. It should be capable of accepting spatial information on salinity, circulation patterns, and nutrients from monitoring or other models.

- **Use conceptual models appropriately in the restoration effort.**

Conceptual models, composed simply of diagrams and descriptions, are a good way to integrate information, communicate ideas, and share understanding on a topic. They are effective organizing tools at the beginning of a study and can provide the initial design basis for simulation models. They might be particularly useful in the assessment protocol development process.

- **Encourage several ecological modeling approaches. Consider, in the context of the suite of capabilities that will be needed, the full range of potentially useful models that may be offered. (Lead--Science Sub-Group)**

Models that can integrate the ecological system across scales appear the most useful, but the door should not be closed to other modeling approaches because modeling science, like the biological world, is evolving, and diversity is the basis for success.

- **Provide an institutional framework, including a home and continuous funding at an increased level, for ecological modeling. (Lead--ITF, with advice from Science Sub-group)**

Models are critical to the application of adaptive management methodology. The Science Sub-Group should propose an institutional framework to support ecological modeling in order to ensure the model development, maintenance, upgrading, and application of models to support assessment and other restoration needs.

- **Ask the right questions.**

The right questions must be asked in order that models are developed that will provide meaningful information for decision making. How the question is framed may make a difference in whether it can be answered and, if answered, translated into effective management.

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APPENDIX

Strategic questions that models are needed to address are listed below in the context of system-wide objectives presented by the Science Sub-Group (1993). The types of models that would be most suitable for addressing each set of questions is listed below them. Addressing strategic questions is important to determining the responses of the system to alternative water management options. The questions will be answered not by modeling alone but by modeling in concert with related field studies and experiments. Investigations are most effective when models and other activities are integrated and modeling activity is initiated at the beginning of the study. The following list indicates the variety of models needed to accomplish the tasks of ecosystem restoration: landscape models, succession models, biomass models, community models, population models, fate models, biodiversity models, etc. Many questions require a system of linked models. Subregion sections point out other issues and strategic questions that modeling is needed to address.

Objective: Restore ecosystem structure and function.

Questions:

What were the essential processes that created, shaped, and maintained the predrainage South Florida landscape and how did that landscape support the rich wildlife once present?

How much spatial extent and landscape heterogeneity must be regained in order to restore the ecosystem structure and function characteristic of the predrainage system, including the support of viable populations of native plants and animals?

How much sheet flow must be restored to significantly improve the habitat value of the system for major indicator organisms and communities in freshwater wetlands and estuaries?

What were the controlling feedbacks between hydrology, geomorphology, and vegetation in the predrainage system that must be operative in order for effective restoration to occur?

Given the influence of basement topography on landscapes, how did hydrologic patterns and rainfall extremes interact with fire and hurricanes to influence fine scale landscape features?

What was the predrainage landscape mosaic and how did it influence hydrologic regime and ecosystem function?

What were the population responses to that mosaic and what are the minimum needs to support healthy, viable populations?

What were the critical characteristics of the predrainage landscape mosaic in terms of hydrologic regime and ecosystem function, and how can these characteristics be recaptured?
How should the hydrologic regime be restored to best restore characteristic species and landscapes? What other actions should be taken in concert with hydrologic restoration?

Given the reduced spatial extent of the central Everglades, can adequate throughflows be restored to support the freshwater inflow needs of Everglades National Park and Florida Bay without disruption to structure and function in the central Everglades?

Can soil rebuilding within the natural Everglades be accomplished by ecosystem restoration? What is the maximum rate of elevation gain that can be expected?

How do timing, frequency, intensity, spatial coverage, and duration of aperiodic events such as fire, freezes, wind storms, and weather extremes (droughts and floods) affect landscape structure? What were the characteristics of these events in the predrainage system?

How does landscape respond to sheet flow vs. channelized flow? An understanding is needed of the differences in response to coarse channel transport as opposed to distributed fine channels of sheet flow--by hydroperiods and hydropatterns, soil moisture, biota, nutrients, and contaminants such as mercury.

How are populations of animals of various sizes and types affected by fragmentation and decreased size of habitat? How might the establishment of wildlife corridors affect their populations? Needed is the determination of minimum size of available habitat required to support populations, as affected by its spatial distribution.

How much of each ecosystem type will result from a given restoration alternative (e.g., pocket wetlands, hydric pine lands, tree islands), and how will each type be distributed across the South Florida landscape?

How and why might restoration of the hydrologic regime restore species or landscapes?

Given the reduced spatial extent of the central Everglades, can adequate gradients and throughput be restored to support the freshwater inflow needs downstream (i.e., in Everglades National Park and Florida Bay) without disrupting the structure and function in the central Everglades?

What processes shape landscape structure, and how are these processes and landscape structure affected by barriers such as roads, levees, and canals?

What are the landscape-scale ecosystem functions in this system, and how are these functions affected by barriers and by water management?

Models: Landscape models linked interactively to hydrologic models so as to influence hydrologic processes and that incorporate biological and physical processes such as vegetation succession, biomass accumulation, soil accretion and subsidence, and battery formation.

Objective: Recover populations of threatened and endangered species and other selected indicator species.

Questions:

What are the habitat requirements for sustainability?

Will restored hydrologic conditions reestablish favorable habitat conditions for threatened and endangered species?
What were the wildlife patterns of the predrainage system and how did they conform to the hydrologic and landscape patterns?

What factors determine nesting site establishment and how are they related to the factors that determine nesting success?

What are the species' hydrologic requirements for feeding and reproduction? How frequently do conditions for successful nesting occur today and how frequently would they have occurred in an undrained system? How frequently would favorable conditions have to occur for long-term population stability (i.e. how many years in a 10 yr period)?

What are the species' habitat requirements and the hydrologic requirements of the habitat, and how has water management affected habitat quality?

What are the relative effects of exotic species, mercury contamination, and hydrology?

What are the other stresses on the populations?

Models: Individual-based models, other population models.

Objective: Restore natural and native biological diversity.

Questions:

How will plant and animal communities respond to landscape mosaics, reestablishment of natural hydrology in various restoration scenarios?

What is species richness of bird communities, fish communities?

How will restoration options affect species richness of selected taxa?

Models: Individual-based species models and community models linked to landscape and hydrologic models.

Objective: Reestablish natural vegetation and periphyton communities.

Questions:

What were the original spatial and temporal distributions of vegetation communities and periphyton communities?

What factors determined those distributions?

What is the relative importance of hydrology and nutrients in determining community structure?

Models: Landscape models and succession models.

Objective: Restore natural rates of productivity throughout the ecosystem.

Questions:

What drives primary and secondary productivity?

What are the fundamental food webs and major energy and material flows in Everglades wetlands, the Big Cypress, and Florida Bay?

Models: Biomass models that incorporate nutrient cycling; nutrient models that are more than simple stochiometric models (nonstochiometric multinutrient models should be undertaken).

Objective: Reestablish sustainable breeding wading bird populations and colonies.

Questions:

Why did South Florida lose 90% of its wading birds when only 50% of wetlands were lost?

Can changed hydroperiods and hydropatterns explain the loss?

Why are wading birds no longer occupying the large nesting colonies in the coastal mangrove area of Everglades National Park east of the Shark River?

Models:

Individual-based models linked to process-based food web models

Nesting colony models to evaluate whether various alternative hydrologic scenarios will result in successful breeding at traditional colony sites.

Models that allow birds to select colony locations under various water management scenarios.

Modeling that addresses not only the trophic dependencies but also other habitat requirements of wading birds; e.g., roosting-nesting habitat.

Models that explore the effect of parasites on fledgling survival and recruitment.

Objective: Halt and reverse the invasion of the South Florida Ecosystem by exotic plants and animals.

Question: What factors control the rate of invasion by exotics?

Models: Landscape models that incorporate dispersion and succession components and project invasion rates under different scenarios of water management strategy and other factors such as climate and fire; probability-based invasion models, with parameters such as seed pool, distance, and susceptibility properties of the site.

Objective: Reduce the input of mercury to the system and its transformation to methylmercury within the system.

Question: Why are the spatial patterns of mercury in largemouth bass not correlated with the spatial patterns of mercury concentrations in soils?

Models: Fate and transport models at landscape level; models that simulate physical transport, chemical transformations, and bioaccumulation in food webs as functions of variable controlling factors.

Objective: Reestablish corridors.

Question: What are the connectivity needs of a given species or guild?

Models: Animal models embedded in the landscape, showing how various landscape patterns affect population processes such as reproduction, migrations, etc.

Objective: Increase the hard coral cover on Florida Keys reefs.

Questions:

What is the longterm effect on coral cover of changes in water quality affecting photosynthesis (i.e., nutrients, light penetration, etc.)?

Does the dependency of reef tract biota on seagrasses and mangroves result in feedbacks that cause declines in seagrasses and mangroves to affect coral reproduction, growth, and survival?

Can spatial patterns of existing coral cover on the Florida reef tract be explained by differential influences of Florida Bay water in different areas?

Models: Succession models, ecosystem models, with reef tract system embedded in larger system of seagrass beds and mangroves in estuaries; links to hydrodynamic models that simulate water transport to the reef tract from Florida Bay and water quality models of Florida Bay.

Objective: Restore natural estuarine and coastal productivity and fisheries.

Question: How much of an increase in estuarine production overall can be expected from a given increase in freshwater flow to Florida Bay?

Models: Seascape models that provide spatially explicit views of estuaries and how salinity patterns, as established by freshwater inflow, overlap with habitat features important to estuarine-dependent species (these models could be used to predict overall abundance of selected species as a function of acreage of overlap of favorable salinities with favorable habitat).

Questions:

How much of an increase in seagrass coverage can be expected from a given increase in freshwater flow or a given decrease in concentration of nutrients?

Could nutrients released from the death and decay of seagrasses alone be responsible for the observed bluegreen algal blooms?

Models: Estuarine models that link seagrass, mangrove, and water column communities; landscape-scale biomass models that include nutrient cycling; fishery population models that relate growth and survival to habitat, salinity, and temperature.

Objectives: Link agricultural and urban growth management with ecosystem management.

Question:

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 landuse configurations?

Models: Landscape-scale ecological models linked to agricultural and urban growth models through hydrologic models. (Prior to model development, review existing methods for calculating growth projections, landuse change, and related water demand and changes in water tables and water management. Evaluate the feasibility of developing and utilizing the proposed model.)

Objective: Restore a system that is self-maintaining with minimum human intervention.

Question: What is the landscape configuration and water regime that will provide a high degree of restoration with the lowest maintenance requirements?

Models: A model that integrates over all spatial scales.

MERCURY IN THE ECOSYSTEM

INTRODUCTION

Beginning with the detection of elevated levels of mercury (Hg) in largemouth bass in 1989 (Ware et al. 1990), it has become increasingly apparent that the South Florida Ecosystem is extensively contaminated. In response to the continuing accretion of reports of significant Hg contamination, the State of Florida has issued human health advisories that ban or restrict consumption of freshwater fishes from over two million acres of the Everglades and the Big Cypress Swamp. Although mercury contamination has been detected at levels of concern in largemouth bass throughout the state (Lange et al. 1993), maximum concentrations found in Everglades largemouth bass (4.4 mg/kg) and bowfin (>7 mg/kg) are the highest Hg contaminant levels thus far reported from Florida waters. Mercury accumulation through the food chain may reduce the breeding success of wading birds (Frederick and Spalding 1994) and the viability of the endangered Florida panther (Roelke et al. 1991).

The sources, distribution, and pathways of transport and transformation of Hg through the South Florida Ecosystem are not well understood. Mercury has been sequestered in the oligotrophic circum-neutral Everglades peats through the 5,000 year period of their development. Subsidence of these soils following drainage, and enhancement of their nutrient status during agricultural conversion, may be mobilizing this geochemical reservoir. The natural Everglades soils were not strongly anaerobic, even though flooded for much of the year (Bachoon and Jones 1992), and increasing anaerobiasis may lead to increases in the importance of organic mercury species in Hg biogeochemical cycles. The 1400 miles of canals now in the system, with their low oxygen content, may provide a primary locale for methylation of Hg and its transport through the system in association with dissolved and finely divided organic matter. Possible external sources include atmospheric deposition from the global and regional background, and deposition from more local fossil-fuel electric power plants, garbage incinerators, paints, medical laboratories, and fossil residues from mercury-containing agricultural chemicals.

Action to control or correct the problem of Hg contamination of the Everglades biota must await a better understanding of the sources and biogeochemical dynamics of the element. The kinds of policy-relevant questions that must be answered are seven in number (US EPA 1993):

- What is the magnitude of the problem? What are the current levels of mercury contamination in various species? What ecological resources of interest are being adversely affected by mercury?
- What is the extent of the mercury problem? What is the geographic distribution of the problem? Is it habitat specific?
- Is the problem getting worse, getting better, or staying the same?
- What factors are associated with, or contribute to, methyl mercury accumulation in sensitive resources?
- What are the contributions and importance of mercury from different sources?
- What are the risks to different ecological systems and species from mercury contamination?
- What management alternatives are available to ameliorate or eliminate the mercury contamination problem?

EPA's Region IV Environmental Services Division (ESD) is conducting field studies intended to delineate the extent, magnitude, and trends of the mercury problem, and to generate data for the initial phase of a formal risk assessment. All these activities are part of a larger interagency effort. The habitat types sampled include canals, ponds, sloughs, wet prairies, sawgrass marsh, and hammocks/tree islands. Canal sampling began in September of 1993, with other tasks initiated in fall and winter of 1993-94. Water, soil, sediment, and biota are sampled using the EPA EMAP (Environmental Monitoring and Assessment Program) probabilistic design. Regional air monitoring is being conducted by the Florida Atmospheric Mercury Study, supported by Florida Power & Light, EPRI (Electric Power Research Institute), Florida DEP, and EPA. EPA Region IV ESD is participating in the development of analytical capabilities for measuring mercury at the parts-per-trillion level in water and air.

The following text describes high-priority research needed to develop an ability to predict the efficacy of policy alternatives, in sections devoted to inorganic chemistry, microbial methylation/demethylation dynamics, ecological dynamics, and aquatic and atmospheric modeling.

BIOLOGICAL TRANSFORMATIONS OF MERCURY

The high levels of methylmercury accumulating in the fish and animals of South Florida may result from increasing inputs of mercury to the system, or from changing environmental conditions that promote the formation and transport of methylmercury. Although some abiotic methylation of mercury may occur, the predominant mechanism for the formation of methylmercury in the environment is microbial (Berman and Bartha 1986). Thus, increases in the concentration of the methyl form of the element indicate either higher available concentrations of inorganic mercury, or higher rates of microbial transformation activity, or both.

Although there is little information about the distribution and transformations of mercury in wetlands, the problem of elevated mercury in fish has been noted in lakes experiencing point source inputs of mercury, recent impoundments, acid inputs, or combinations thereof (Hakanson et al. 1988, Jackson 1988). Methylmercury, which constitutes a small fraction of total environmental mercury, is the predominant form of mercury present in contaminated fish (Westoo 1972) and is bioaccumulated at high rates (Boudou and Ribeyre 1985). Methylmercury, introduced as a point source into Minamata Bay, was also identified as the compound responsible for the widespread human toxicity associated with consumption of local fish in Minamata, Japan in the late 1960's (D'Itri 1972).

More commonly, however, environmental mercury contamination cannot be attributed to external sources, but rather stems from alterations of environmental conditions that mobilize mercury and promote uptake via methylation. Widespread mercury contamination was identified in lakes in Scandinavia, eastern Canada and north central United States. (Hakanson et al. 1988, Jackson 1988); surveys of affected lakes implicated acidification of poorly buffered lakes and/or recent impoundment as contributing to elevated mercury levels in fish.

Background

Are the increases in methylmercury in fish and animals in the Everglades due to increases in inputs of mercury or to internal transport and transformation in the system? Examination of the available data and consideration of the hydrological and land use changes that have occurred suggest that either or both phenomena may contribute to the current levels of contamination.

The distribution of total mercury in soils and sediments of Everglades (Delfino et al. 1993) indicates an increase in the accumulation rates of mercury for the 90 years since the turn of the century, with pronounced increases dating from 1940. The similarity of these data to trends in lakes of north central U.S. and Sweden, despite differences in climate, hydroperiod, vegetation and location, implicates the worldwide increases in mercury inputs accompanying industrialization. However, the distribution of increases in accumulation rates within the Everglades is not uniform; water conservation areas 1 and 2 have the highest increases, implicating either localized sources or internal transport and transformation processes.

If present and past conditions in the Everglades are compared with those factors known to control the rates of mercury transformations in other surface water systems, it can be seen that the changes of the last century have largely been in the direction of promoting mercury methylation.

The net rate of mercury methylation in the environment reflects the relative rates of two microbial processes: methylation and demethylation. Methylation is carried out by sulfate-reducing bacteria in both freshwater and saltwater systems (Compeau and Bartha 1985, Gilmour et al. 1992). Demethylation can occur by two or more pathways (Oremland et al. 1991); the importance of each pathway under different environmental conditions has not been well-characterized, but may result in different net rates of methylation.

Low levels ($< 1\ \mu M$) of sulfate in freshwater systems inhibit the rate of methylation (Gilmour et al. 1992). The increases in mercury methylation observed in acidified temperate lakes can be attributed to sulfate fertilization rather than to direct pH effects. The high levels of sulfate in marine systems also inhibit methylation (Winfrey and Rudd 1990) by promoting the precipitation of mercury as sulfides. The concentrations of sulfate in the waters of the Everglade (5--170 mg/L (Stober et al. 1994)) span the 20--40 mg/L concentration range thought to be optimal for mercury methylation (Gilmour and Henry 1991). Thus, although sulfate concentrations in the Everglades have probably not changed appreciably (the high concentrations relative to other freshwaters are due to underlying mineralogy, rather than acid rain inputs), the high levels of sulfates may predispose the system to respond strongly to the removal of other limitations on methylation.

Other factors that influence the rate of methylation include temperature, dissolved organic carbon and aeration status. Given that most studies of microbial methylation have occurred in mid- to high-latitude lakes, it is likely that the potential rates of methylation in the Everglades may exceed those measured in temperate systems.

The aeration status of regions within South Florida changed in response to changes in hydrology and in oxygen demand, largely caused by loadings of inorganic nutrients. Drainage of peat soils has caused oxidation of the organic matter from the soils, especially where microbial respiratory activity has been supported by nutrient additions. The fate of any mercury that was associated with such soils is not known. Canalization and eutrophication have created anaerobic zones within the water column that had previously been limited in extent, giving rise to areas of potentially high methylation activity. Additionally, eutrophication has increased the activity of sediment microbial populations, making the sediments more strongly anaerobic. These conditions favor the activity of the sulfate-reducing bacteria responsible for the methylation of mercury. Thus, eutrophication may stimulate methylation by direct and by indirect mechanisms.

The alteration of hydrology and nutrient status may also change the nature and composition of the organic matter cycled and transported within the system. In oligotrophic wetlands, much organic carbon is tied up as lignocellulose, or plant detrital material, which cycles slowly. Under more eutrophic conditions, algal growth and higher microbial activity increase the lability of the carbon. Increases in organic matter generally support higher microbial activity, but may also complex the mercury, decreasing its availability for methylation. It is difficult, therefore, to predict the direction of change that may result from changes in the character, amount and distribution of organic matter.

Questions

Given the role of methylmercury in the uptake and accumulation of mercury by biota, an understanding of the formation and fate of the compound is essential for the development of risk assessments and ameliorative strategies. Such an understanding must be based on a research program that includes the following activities:

- Identify the environmental factors that influence the rates of microbial methylation and demethylation. Determine how these factors are constrained by present conditions and historical changes in the hydrology and land use of the Everglades.
  - nutrients
  - oxygen
  - organic carbon
- Investigate the alteration of organic matter, in response to changing nutrient and oxygen status. Determine the effect of organic matter on the availability of mercury for microbial transformations, and the activity and composition of microbial populations that carry out the transformations of mercury.
- Characterize ecological zones and/or land uses with respect to the conditions that influence that rates of methylation and demethylation. Incorporate ecological characterization into the construction of mass balances and transport models for mercury in the Everglades.

- Investigate the impact of alterations of aeration status, such as that resulting from periodic inundation and dewatering of agricultural lands, on the release and transformation of mercury.
- Determine forms of organomercury other than methylmercury that may occur in the waters and sediments of the Everglades. Investigate the implications of other organomercury forms for transformation pathways.
- Determine the importance of demethylation processes under different aeration regimes and in different ecological zones. Determine the impact of different demethylation pathways on the net rate of methylation.

A research program that addresses these questions will support the construction of a biogeochemical model integrating the methylation of mercury with carbon, nitrogen, phosphorus and sulfur cycles. Such a model will link microbial activity with environmental parameters for testing of explanatory hypotheses for fate and transport of mercury and predicting the consequences of mitigation strategies.

Approach

Two complementary approaches are essential for resolving the sources and fate of mercury within the Everglades: determination of distributions, and experimental investigations of transport and transformation processes. Both efforts are critical for distinguishing among the hypotheses that have been proposed to explain the high concentrations of methylmercury in biota. Recent and ongoing research focusses on determining the extent of mercury contamination, the current distribution of mercury species in sediment, water and fish, and historical distribution of total mercury in sediments.

Region IV of the U.S. EPA is conducting a researeh program with the support of other federal and state agencies. This program, R-EMAP, uses a probabilistic sampling strategy to determine the distribution of methylmercury and total mercury in water, sediments, and fish, as well as pertinent environmental parameters (e.g. temperature, dissolved oxygen, nutrient and sulfate concentrations, alkaline phosphatase activity, conventional soil parameters). Sampling efforts have been designed to support the testing of specific hypotheses for the distribution and transport of mercury, e.g., sampling efforts have followed longitudinal transects in canals and across nutrient (especially phosphorus) gradients. Preliminary data on mercury in fish indicate a strong gradient from north to south, with the highest concentrations of mercury occurring in the Everglades below the water conservation and agricultural areas, and due west of the highly populated coastal ridge.

This effort has also supported a laboratory study to determine the effect of nutrient additions on methylation rates in microcosms (Kavanaugh and Barkay 1992). Methylation and demethylation were shown to be stimulated by additions of phosphorus to Everglades soils.

A field study, jointly funded by SFWMD, USGS, and FDER, was conducted between January 1992 and February 1993 to determine historical baseline concentrations of mercury in Everglades and Okefenokee sediments, post-industrial changes in sediment mercury accumulation, and the spatial distribution of mercury throughout the Everglades (Delfino et al. 1993). This study found that average mercury concentrations in the surface sediments ($n=51$) was 121 ng/g and that surface concentrations averaged 2.5 times higher than concentrations deeper in the profile. Organic mercury averaged 52% of total. Mercury accumulation rates started to increase ca. 1940, coincident with the mid-century alteration of hydrology and agricultural and urban development of southern Florida.

Research Projections and Needs

The principal research needs include a program of experimental investigations to elucidate the environmental controls on microbially-mediated transformations of mercury, and to support the construction of models for the fate and transport of mercury within the system. In addition to the limited process investigations accompanying the R-EMAP efforts, experimental work is being supported by USGS, EPA/ORD and SFWMD.

A mercury study plan has been developed to address concerns about mercury transformations and mobilization that might accompany the Everglades Nutrient Removal (ENR) Project and the Stormwater Treatment Areas (STA) proposed for cleansing of agricultural runoff. (SFWMD 1994). Although the ENR is designed primarily to remove phosphorus, it also presents an excellent opportunity to test hypotheses regarding mercury transformations, especially those pertaining to effects of eutrophication and alteration of aeration status. In addition to the manipulations planned for the ENR as a whole, microcosms and sediment material derived from the area will be suitable for testing of responses to different concentrations of phosphorus, or other experimental treatments. The ENR has been designed to mimic the hydrology of Water Conservation Area 2A; no additional manipulations, physical, chemical or biological, are planned for enhanced removal of nutrients. It is projected that long-term nutrient removal will occur as a consequence of peat accumulation under anaerobic conditions; it is not known whether mercury will be sequestered or released under those conditions (Sugar Cane Growers Cooperative 1994).

As part of U.S. EPA and Florida DEP permitting requirements, total recoverable and methyl mercury will be monitored at the inflow and outflow of the ENR site, as well as from a location upstream of the outflow in the L-7 Borrow Canal. Requirements of the permit also stipulate that body burdens in fish and shellfish be monitored for two years of operation, and that 28-day bioaccumulation assays be performed quarterly. Fluxes of total, particulate and dissolved mercury will be measured to determine the mass balance of mercury species, as will the rates of mercury accumulation in sediments. An atmospheric mercury monitoring station, similar to those operated by the Florida Atmospheric Monitoring Study, will be constructed near the site to measure atmospheric fluxes to the area.

The SFWMD (1993) has also proposed studies under the Section 319 Nonpoint Sources Grants Program to determine the effects of Best Management Practices implemented in the Everglades Agricultural Area on mercury loadings to the Everglades. Three categories of practices will be evaluated: traditional on-farm changes in water and fertilizer application practices, buffer strips or retention ponds, and a large-scale constructed wetland to be managed by a consortium of farmers.

The U.S. Geological Survey has proposed to investigate the interactions between hydrological and chemical processes and the distribution of methylmercury, focussing on the speciation and complexation of mercury. They also propose to investigate the controls on methylation processes by manipulating sediment cores from canal and marsh locations within the Everglades. This effort will be coordinated with other federally-funded projects, including co-location of sampling with R-EMAP sites.

In addition to the REMAP sampling effort supported by U.S. EPA Region IV, EPA plans to support basic research into the mechanisms that control net rate of methylation of mercury with the goal of developing models for the kinetics of the process. Two projects have been funded: one will investigate the response of demethylation processes to environmental factors and the resultant effect on net methylation rates, and the role of methylating agents; the second will investigate the environmental processes that control the rate of methylation. Efforts will be made to determine methylation/demethylation rates in materials derived from R-EMAP sampling sites. The results of these experimental investigations will be incorporated in the development of biogeochemical models that link microbial transformations of mercury with carbon, sulfur and nutrient cycling.

The proposed integrated research program also includes the creation of a GIS database for environmental parameters that may control transport and transformation of mercury in South Florida (e.g. soil types, vegetation, hydrology, agricultural crops, wildlife distribution, fertilizer and pesticide applications, nutrient concentrations, water chemistry, and mercury concentrations in soils, sediments, and water).

Models for the rates of mercury transformations, as derived from the process-based research, must be tested and implemented based on specific geographic data. Initially, a mass-balance approach could be used to estimate mercury transformations associated with large-scale land use and ecological zones. Subsequent efforts would implement mercury transformation models within the mercury cycling and transport models.

Additional research needs include the appropriate characterization of ecological zones and land uses, both present-day and historical, within the Everglades with respect to conditions that influence the rates of M/D, in order to integrate and analyze data on the forms and concentrations of mercury.

Specific research needs that are not being directly addressed in current or proposed research plans include: the nature of the organic matter (e.g., periphyton vs. detritus of emergent plants) that serves as the microbial substrate for methylation, as it is impacted by altered nutrient and aeration conditions, the effects of periodic inundation of agricultural lands, and the importance of organomercury species other than methylmercury.

ABIOTIC MERCURY BIOGEOCHEMICAL AND TRANSPORT PROCESSES

Mercury occurs in the environment as a number of species which display species-dependent partitioning, bioavailability, rates of interconversion and overall fate and transport. This section outlines ongoing and future research on those aspects of environmental inorganic mercury speciation that must be understood to assess mercury bioavailability in South Florida.

Major Issues and Problems

Although unacceptable mercury bioavailability may be widespread in the region, observed mercury concentrations in soils/sediments do not appear to be present at exceptionally high concentrations (Long and Morgan 1990, Cantillo et al. 1993, Delfino et al. 1993). Additionally, assuming that monomethylmercury (CH_3Hg^+) is the dominant bioavailable species and assuming that South Florida is comparable to other environs, mercury methylation is likely to be most significant in surficial sediments (Jernelov 1970, Billen and Wollast 1973, Callister and Winfrey 1985). A major question is: "What is the source of the mercury in the surficial sediments that becomes available for methylation?" Is it mercury that ultimately is derived from external sources that are freshly deposited in the sediments, or is it mercury migrating from deeper strata within the sediments? Answering these questions requires a technical capability for assessing mercury migration in sediments, which, in turn, will require the ability to assess porewater mercury concentration gradients established by background sedimentary biogeochemical processes. Technical projects designed to assist in answering the above questions focus on employing recent scientific advances in the understanding of sedimentary processes and speciation-dependent binding with organic carbon.

Background

Of the various environmental species of mercury discussed in the scientific literature, monomethylmercury (CH_3Hg^+) is the dominant species associated with bioavailability and biomagnification (Driscoll et al. 1993, Zillioux et al. 1994). Monomethylmercury typically represents ca. $<1\%$ to 10% of the total mercury in a given water sample. Divalent mercury (Hg^{2+}) is the most thermodynamically stable species in oxic environments; it also may represent the dominant form of mercury in the water column and the dominant atmospheric species deposited either through dry or wet deposition. Elemental mercury (Hg^0) is presumably formed primarily through microbial reduction and, because of its high vapor pressure (Lindquist and Rohde 1985), may be the most significant volatile species lost to (and present in) the atmosphere. Dimethylmercury ($(CH_3)_2Hg$) is another volatile species (Lindquist and Rohde 1985) that presumably can be formed in sediments, albeit at rates 6,000 times less than that of monomethylmercury (Wood 1974).

There is ample scientific evidence that many of the environmental mercury species are intimately associated with natural organic carbon (Billen and Wollast 1973, Andren and Harriss 1973, 1975, Alberts et al. 1974, Lindberg and Harriss 1974, Robertson et al. 1987, Gill and Bruland 1990, Xu and Allard 1991, Zillioux et al. 1993, Hurley et al. 1994, Driscoll et al. 1994). Unfortunately, a fundamental (mechanistic) understanding of mercury partitioning with natural organic carbon is not currently available; absent this understanding a reliable analysis of the probable effect of restoration and management actions on Hg dynamics cannot be accomplished.

The two major issues to be addressed in the near term include the development of regional-specific process models to describe mercury species-dependent binding with naturally occurring organic matter, and the development of regional-specific methods to assess mercury migration in sediments.

Current Research

Current research on the abiotic processes relevant to mercury speciation is primarily being obtained via an Interagency Agreement between the U.S. Environmental Protection Agency (US EPA) and the U.S. Geological Survey (USGS). This work is developing an experimental dataset of mercury binding with natural organic carbon (obtained from the South Florida Region), developing fundamental process-based models of the observed mercury species-dependent binding behavior, and investigating the potential migratory behavior of mercury in sediments from the South Florida Ecosystem. This last aspect builds (in part) on the application of a steady-state sediment model produced by an existing cooperative agreement between the Environmental Research Laboratory-Athens and the Georgia Institute of Technology (A General Transport Reaction Model for Freshwater Sediments; Van Cappellen and Wang 1994).

Research Needs

Findings obtained from the current research will be applicable as general, process-based methods for assessing mercury speciation and sedimentary migration. Because these findings will be the products of fundamental research work, future applications will involve extrapolating relationships derived from carefully controlled systems to larger scales, which will require an overlay of statistical uncertainty.

ECOLOGICAL EXPOSURE AND EFFECTS OF MERCURY

Over the last twenty years considerable attention has been focused on monitoring and investigating the bioaccumulation and ecological effects of mercury. Although several reviews of the ecological exposure and effects of mercury (Gavis and Ferguson 1972; Eisler 1987; Richman et al. 1988; Depledge and Rainbow 1990; Sorensen 1991; Jonnalagadda and Prasada Rao 1993; Zillioux et al. 1993; Driscoll et al. 1994; Zalups and Lash 1994) have appeared, many aspects of these topics remain unknown or unsynthesized.

Major Issues and Problems

Mercury contamination in south Florida is a well documented problem and may be an important contributing factor in the decline of wading bird populations and other top predators such as the Florida panther. If the restoration of the South Florida Ecosystem to be realized fully, decision makers must be able to quantify and assess the ecological risk posed by mercury in conjunction with other system stressors.

Background

The ability to analyze and predict the mercury bioaccumulation is necessary in order to define realistic dietary exposures to wildlife, to assess the potential for significant biotic transport of mercury, and to predict the onset of residue-based effects that result from chronic or varying temporal/spatial exposures.

Two basic approaches have been used to quantify the bioaccumulation of environmental pollutants in aquatic and terrestrial biota. The first of these assumes that organisms quickly achieve a chemical equilibrium with respect to a particular medium or route of exposure. For aquatic biota, this reference medium is generally taken to be the water. For terrestrial plants, this medium may be either the soil or possibly the air. In the case of terrestrial animals, the reference medium may be the soil or, more commonly, the animal's principal prey or food. This approach uses bioconcentration or bioaccumulation factors (BCF and BAF) to estimate chemical residues in biota from measured concentrations in the appropriate reference media. BCFs for several compounds of mercury have been reported to

vary between $10^{2.4}$ and $10^{6.7}$ for a variety of biota. Because bioaccumulation/elimination half-lives of most mercury compounds are extremely long, many of the BCFs reported to be less than 10^4 do not represent true equilibrium values. For example, half-lives of methylmercury in most vertebrates vary from hundreds of days to years. Moreover, these half-lives generally will depend on body size and other environmental variables such as temperature.

The second approach assumes that chemical accumulation is a slow process and that the organism's chemical burden is not necessarily in equilibrium with a particular exposure medium. This approach, which appears to be more appropriate for mercury, estimates chemical bioaccumulation using mathematical models that explicitly model the chemical's uptake, metabolism, excretion, and biodilution as a function of the organism's environmental exposures.

Many researchers have studied the bioaccumulation of mercury in diverse biota under natural field conditions. Many of these studies have demonstrated a strong interrelation between the organism's body size and its body burden of mercury. This trend is particularly evident in fish, mollusks, and aquatic mammals. At least two factors contribute to this relationship. The first is the association of increases in body size with increasing longevity and hence increased exposure. Increasing body size also increases an animal's exposure to mercury along spatial dimensions because the sizes of territories and home ranges of many vertebrate species correlate well with their body size. The allometric relationship between body size and feeding also influences this relationship. That large organisms consume more prey than do small organisms obviously increases their exposure probabilities, as do size-dependent home ranges and territories.

A third factor contributing to this trend is that as many predators grow they generally consume very much larger prey. Although this trend is particularly evident in predatory fish, other predators, including snakes and birds, also demonstrate this trend. If the mercury concentration in a predators's prey displays a positive correlation with its body size, predators that exhibit size-dependent selectivity of prey will be subject to ever-increasing mercury exposures. These facts, like the preceding kinetic considerations, suggest that analysis and characterization of mercury contamination in the South Florida Ecosystem must be performed using dynamic, process-based bioaccumulation models.

This conclusion is strengthened by the findings of several authors that total body burdens of mercury in fish and other aquatic biota are correlated with environmental variables not accounted for in the BCF/BAF approaches. For example, mercury burdens are often negatively correlated with water pH and DOC. Whereas the negative correlation between the body burden and ambient pH is generally attributed to the reduced methylation of mercury under alkaline conditions, the negative correlation between the body burden and ambient DOC is generally believed to result from reduced bioavailability of mercury as it binds to sulfhydryl groups of organic molecules. Some authors have demonstrated significant positive correlations between fishes' total mercury body burden and lake size. Because large lakes generally are situated in larger watersheds than are small lakes, and because atmospheric deposition of mercury often appears to be a significant input of mercury to surface water, large lakes generally would be expected to have higher mercury concentrations than would small lakes. These positive correlations are thus unsurprising.

Most ecological risk assessments for mercury have been based upon exposure-based endpoints such as the LC_{50}; these toxicological benchmarks have been reported for a wide variety of biota. Depending on the biota being considered, however, these data may differ by 2 or 3 orders of magnitude. Such variations are not surprising, however, since any factor that influences the rate of mercury accumulation within an organism will affect its observed LC_{50}. Thus, for example, factors that affect the respiration of aquatic biota, and hence their gill exchange, should also affect the LC_{50}. Thus, it is not surprising that the LC_{50} values observed for most aquatic biota are generally decreasing functions of body size, temperature, and duration of exposure. For marine biota, LC_{50} also depend on salinity.

Although most ecological risk assessments for environmental contaminants traditionally have been founded on exposure-based endpoints such as LC_{50}s and EC_{50}s discussed above, the effects of chemicals on organisms are not caused by the chemical in the environment per se, but rather by the chemical that is accumulated within the organism. Exposure-based toxicity endpoints generally address only a single route of exposure under constant exposure conditions. For example, acute hazard assessments for fish usually are based on 96-hr LC_{50}s for constant water concentrations. Under field conditions, however, fish will accumulate chemicals not only from the water but also from their prey that also become contaminated. If dietary exposures are more significant than direct aqueous exposures, there is no a priori reason to assume that hazard assessments based on the LC_{50} would be protective of field populations. Even if both dietary and aqueous toxicity benchmarks are known, there are no rules-of-thumb to determine which toxicity benchmark should be used for all fish or all field exposure scenarios, since the relative significance of various routes of uptake depends on the exposure scenario being considered. The only objective way to address the consequences of realistic ecological exposures and interactions and to reduce the uncertainties associated with ecological risk assessments is to deal directly with the kinetics of chemical bioaccumulation in organisms and establish the needed residue-based endpoints.

Major Research Questions

Major research questions regarding mercury bioaccumulation include:

- What is the partitioning and binding behavior of different mercury species within organisms?
- Is the heterogeneous distribution of mercury among tissues a kinetic or equilibrium phenomenon?
- How should mercury bioconcentration in plants be modeled to describe the trophic exposures to herbivorous wildlife?
- How does prey availability, size-dependent home ranges, and ontogenetic changes in prey preferences influence the bioaccumulation of mercury in aquatic and terrestrial wildlife?
- How does the spatial and temporal distribution of habitat influence the bioaccumulation of mercury in highly mobile and migratory wildlife?
- What metabolic transformations of mercury occur that affect its uptake, internal distribution, or excretion?
- Can mercury bioaccumulation be modeled with sufficient accuracy without modeling the concurrent bioaccumulation of other metals that compete for the same sulfhydryl binding sites?
- What water quality parameters influence the bioaccumulation of mercury in the Everglades aquatic communities? What fate and transport models can be used to simulate these variables?

Major research questions regarding the ecological effects of mercury include:

- What bioconcentration or bioaccumulation models are available to estimate residue-based toxicity endpoints from previously published exposure-based endpoints?
- What residue levels affect the feeding, growth, reproduction, and mortality of South Florida wildlife? What indicator species should be selected for study?
- How should the accumulative effects of multiple mercuric species be quantified? How should the accumulative effects of mercury, other metals, and organics be quantified?
- What factors ameliorate mercury toxicity (e.g., selenium species)? How should these factors be incorporated into the mercury modeling program?

Approach

To estimate accurately the ecological effects of mercury in the South Florida Ecosystem a suite of process-based models that are supported by user interfaces and databases must be developed to describe

- the nominal trophic dynamics and habitat utilization of vertebrate and invertebrate wildlife in wetland and estuarine ecosystems,

- the effects of hydrology, water quality, and vegetative habitat structure alterations on these ecological processes,
- the bioaccumulation of mercury and other persistent organic chemicals and metals in wetland and estuarine biota, and
- the direct and indirect effects of chemical contamination on the structure and function of wetland and estuarine ecosystems

Conceptual models describing the foodwebs and habitat utilization of South Florida ecosystems should be documented to delineate the principal ecological interactions and forcing functions needed to sustain viable populations of the major wildlife species. While most vertebrate wildlife should be treated as the individual species, invertebrate wildlife could be treated as functional groups. Aquatic and terrestrial flora should be characterized at a scale of resolution appropriate to describing the trophic and habitat dependencies of these wildlife components.

Physiologically-based models that are currently being developed for south Florida wildlife already address some of the above needs and should be continue to be supported. ERL-Athens will be modifying the FGETS (Food and Gill Exchange of Toxic Substances) bioaccumulation model to analyze the bioaccumulation and effects of mercury in the South Florida Ecosystem. FGETS is a process-based model that describes the bioenergetics and bioaccumulation of organic chemicals of arbitrarily specified age-structured fish assemblages. Because of its generalized structure, other wildlife components can be readily incorporated into the existing FGETS foodweb structure.

Habitat suitability models for vertebrate wildlife species will be reviewed and used as an integral part of this research. These models should be used as the initial, but not necessarily final, frameworks to address the foraging, nesting/reproductive, and roosting habitat requirements of vertebrate wildlife species of concern. A realistic forest stand model (e.g., FORET, FOREST, JABOWA, KIAMBRAM, SILVA, SWAMP) will be integrated with a wetland foodweb model in order to simulate the structural characteristics of wetland vegetation required by wetland vertebrates for food, shelter, and reproduction. This stand model should be responsive to hydrologic alterations, fire, local and regional climatic factors, and episodic disturbances such as hurricanes.

Wetland and estuarine community models should be validated piece-wise using literature data and field and laboratory studies planned as part of the Everglades Restoration Project. As various submodels are validated, databases of ecological, morphological, and physiological parameters required by the submodels will be compiled to facilitate rapid and effective model parameterization. User interfaces also will be developed.

AQUATIC MERCURY FATE MODELING

Conceptual models and process submodels of the biogeochemical cycling of mercury, properly distilled, provide a powerful basis for operational site-specific models. Such mercury fate models may be constructed *de novo*, or may be built upon the framework of existing chemical transport and fate models. Several existing chemical models treat environmental transport and chemical transformation processes in a general manner that can be used for many organic and inorganic chemicals. These models can be modified to handle the special transfer and transformation reactions that affect the mobility and speciation of mercury. This discussion encompasses the development and application of a mercury fate model to specific locations in the Everglades.

Major Issues and Problems

Mercury fate is multimedia in scope. Because of the size and complexity of any general multimedia mercury model, efforts have generally been directed to individual media, although it is recognized that mercury can exchange between the atmosphere and surface water. Although aquatic food web bioaccumulation models are often formulated separately from surface water models, the nature of mercury dynamics requires a direct connection

between the models. The major issues in constructing a mercury model are the devising of a proper and practical representation of the complex physical, chemical, and biological reactions, and integration of the major components into an operational framework. The major issues in operating a mercury model are proper parameterization, given measurement and model uncertainty, and spatial and temporal variability.

Background

Several modeling approaches for describing fate of mercury in watersheds have been undertaken. Recent modeling efforts have usually been based on several simplifications. Some are simplistic in their representation of mercury chemistry. Others, although able to represent some of the complex mercury chemistry, can represent only simple physical environments. Currently, a general modeling framework for the mechanistic simulation of transport and fate of mercury in complex aquatic environments does not exist.

The Mercury Cycling Model (MCM) mechanistically simulates the transport and transformations of mercury in natural lakes (Hudson et al. 1990, Hudson et al. 1993). Four mercury components are simulated: Hg(0), Hg(II), MeHg, and Hg(inert). Kinetic transformation reactions are linear with respect to the mercury components, but may be modified by other water quality variables. The model handles aqueous complexation using compartment-specific parameters and equilibrium constants. A simple food chain model is included with direct transfers of mercury through a linear four step food chain composed of phytoplankton, zooplankton, planktivorous fish, and piscivorous fish. MCM is spatially simple, calculating mercury fate and bioaccumulation in three compartments: epilimnion, hypolimnion, and benthic sediment.

MERC4 (Martin 1992) is based on a generalized compartmental modeling system that allows complex physical representation of water bodies with up to 500 segments that can be linked with hydrodynamic models (Ambrose, et al. 1987). MERC4 mercury components and reactions were set to emulate MCM; Hg(0), Hg(II), MeHg, and Hg(inert) are simulated with aqueous complexation, solubility, sorption, and kinetic transformation reactions. In addition MERC4 conducts mass balance calculations for three user-defined solids. The current version of MERC4 does not include food chain components. It is presently undergoing limited in-house and external testing, but has not been formally reviewed or released. A beta-test version of MERC4 was modified by PTI, Inc., to include simple bioaccumulation routines, and successfully applied to Onondaga Lake, an urban lake in the northeast. Fish Bioenergetics Model 2, developed at the University of Wisconsin Center for Limnology, was used to estimate mercury accumulation in the aquatic food chain based upon prey consumption, waste production, mortality, and fish growth. The aquatic food chain is composed of phytoplankton, zooplankton, macroinvertebrates, and seven fish species, including planktivores, demersals, and piscivores.

RMA-4 is a simple two-dimensional, depth-averaged finite-element water quality model that handles contaminant transport and first-order decay (King and Rachiele 1989). This model is linked with a compatible hydrodynamics program and software for mesh generation and post-processing. The University of California, Davis, is modifying the RMA-4 model to simulate sediment and mercury components, including Hg(0), MeHg, and Hg(II). Both MeHg and Hg(II) are allowed to distribute between dissolved and particle-bound forms. Biological and chemical transformations of mercury from one component to another are modeled as either zero- or first-order sources or sinks. Among the transfer and transformation processes modeled are methylation, demethylation, volatilization, sorption-desorption, sedimentation, reduction, biouptake, atmospheric deposition, and diffusion.

Current Research

Both UC Davis and AERL plan to pursue modeling investigations of mercury transport, fate, and bioaccumulation in Clear Lake. In a current contract, UC Davis is developing a general mercury food web model and parameterizing it for Clear Lake. UC Davis plans to incorporate this model into a general biogeochemical modeling system that simulates aqueous and benthic inorganic and methylmercury concentrations throughout Clear Lake, and exercise the modeling system to investigate the consequences of potential remediation options. The resulting model will describe a simple aquatic food web that incorporates transfers to piscivorous birds and

mammals. This model will be parameterized and validated with data from Clear Lake, but will be designed so that it could be applied to other aquatic systems by respecifying parameter values.

AERL is funding an NRC associate to investigate model linkage issues, particularly interactive coupling of hydrodynamic, water quality, and bioaccumulation models through parallel processing. Clear Lake will be the test system for this work. In addition, AERL has made plans to study mercury transport and fate within canal systems in the Everglades, in cooperation with EPA Region IV REMAP studies. The modeling component of this study will begin with the modeling package arising from the Clear Lake study. Two modeling tasks have been identified.

The goal of the first is to predict the fate of mercury species in the sediments, water, and fish of a selected canal system in the Everglades based upon known sources. The first step in this task is to calibrate flow, sediment transport, and mercury transport in the selected canal within the Everglades. Based upon the results of the initial application and ongoing studies, the mercury transport model will be revised and extended. Food web bioaccumulation will be simulated using the food web model that was originally developed for Clear Lake.

The goal of the second modeling task is to predict the fate of mercury species in the sediments, water, and fishes of the Everglades based upon known sources. The first step is to identify and code a simplified mercury dynamics model for linked canal-wetland-sediment compartments. This simplified model will be applied in a GIS framework to the Everglades system as a whole, with proper hydrologic linkages specified from existing models. Issues of scale and model linkage will be investigated in both tasks.

Research Needs

Some of the existing mercury models are simplistic in their representation of mercury chemistry, while others only represent simple physical environments, while incorporating a more realistic representation of mercury chemistry. MCM has become a standard in its handling of mercury components and reactions. Operational models are needed that can represent a complex physical environment, and handle complex mercury chemistry in a manner similar to MCM. These are still under development and testing, and require linkage with a food web component.

Reliable diagnostic or predictive modeling depends to a great extent on accurate process descriptions. The most important areas of process uncertainty expected to affect overall mercury fate are highlighted below. The proper application of these models requires the specification of input data that describe and parameterize the environment being investigated. Data needs are also discussed below.

Site-specific data needs. For aquatic fate models, data needs include hydrogeometry, advective flows, dispersive transport, external loadings and boundary concentrations, and various chemical constants and environmental parameters. The chemical constants and environmental parameters required for mercury modeling will depend upon how the speciation and transformation processes in the model are formulated. Some environmental parameters that are expected to be important include pH, dissolved oxygen, dissolved organic carbon, sulfide, sulfate, and TDS.

Methylation and demethylation kinetics. The methyl forms of mercury are known to bioaccumulate strongly and provide the most risk to humans and wildlife. Most of the mercury delivered to the aquatic environment is inorganic. The internal production of methyl mercury, then, is a crucial process in any mechanistic mercury fate model. The form of the kinetic equations, the dependencies on environmental parameters, and the rate constants must be described and tested in a variety of aquatic environments.

Complexation with fine organics, DOC, and colloids. Those species of mercury that are complexed with dissolved or fine organic material are mobilized for transport, but may be shielded from some loss processes. Good process models should be able to describe the binding capacity and strength of this material for various species of mercury. In addition, the biogeochemistry of DOC and fine organics in canals and wetlands must be described. Formation and loss processes must be quantified.

Sorption onto sediments. Those species of mercury that sorb onto suspended sediments can be deposited into the benthic environment and transformed or buried. Process models are needed that can accurately describe the sorption process for the important species of mercury. In addition, data are needed to characterize the sediments in South Florida so that their sorption capacity can be modeled. Sediment transport processes through canals and wetlands must be described, especially for silt and clay fractions.

Uptake by aquatic plants, phytoplankton. The amount of partitioning or uptake of mercury into the base of the aquatic food web drives the subsequent bioaccumulation. Research is needed into how this can best be represented, the coefficients or rates for mercury species entering phytoplankton and plants, and what environmental parameters might affect the kinetics.

Spatially distributed food web model. The current generation of food web models describe bioaccumulation in one place. For large or long aquatic systems with gradients of exposure concentrations, a spatially-distributed food web model will be necessary. Such a model would allow the user to specify a range for each fish species and age class. Plankton would be carried through the spatial network by advective currents. Overlapping ranges would be taken care of properly. Part of this research effort requires the accurate biological description of the site being investigated. Modeling technology must be developed to facilitate the representation of the biology and to perform the bookkeeping properly.

Parallel linkage of aquatic fate and food web models. Traditional aquatic chemical fate models do not include an internal food web. Bioaccumulation calculations are executed following the aquatic fate calculations, as the aquatic concentrations are not usually affected significantly by the food web. Aquatic fate and bioaccumulation cannot be treated separately for methylmercury. Models such as MCM and Meridian have food web equations built in, and the Wisconsin bioenergetics model has been used as a subroutine to MERC4. A general modeling linkage should be developed to allow the operation of specialized food web models with spatially distributed aquatic fate models.

ATMOSPHERIC MERCURY FATE MODELING

Atmospheric models of mercury transport and transformation are being constructed and used to determine human exposure to mercury from various anthropogenic sources. This section reviews operational atmospheric mercury fate models that could be adapted for use in South Florida. Present atmospheric mercury fate models are built upon the framework of existing chemical transport and fate models. These models can be modified to handle the special transfer and transformation reactions of mercury and its compounds. This chapter focusses on one long-range model that is being used to examine mercury transport, along with some of the process and data uncertainties encountered.

Major Issues and Problems

Atmospheric models are generally used to estimate direct human exposure and to provide loadings to surface water and soil. Volatile exchanges, however, could provide significant loadings from watersheds to the air. Although terrestrial and aquatic fate models are often formulated separately from atmospheric models, the nature of mercury dynamics requires an interconnection between these models that is achieved only crudely at present. There are significant uncertainties about atmospheric mercury chemistry that could affect the accuracy of descriptions of deposition of mercury species at the local and regional scale.

Background

Following a decade of development in Europe and the United States, the REgional Lagrangian Model of Air Pollution (RELMAP) was produced in 1984 (Eder et al. 1986, Clark et al. 1992). RELMAP is capable of simulating concentrations and wet and dry deposition patterns of SO_2, SO_4^{2-}, and fine and coarse particulate matter. In addition to the main model program, the complete RELMAP modeling system includes 19 preprocessing

programs that prepare gridded meteorological and emissions data for use in the main program. Currently, the RELMAP is supported by EPA's Atmospheric Research and Exposure Assessment Laboratory.

The original sulfur version of RELMAP was recently modified to permit the simulation of atmospheric mercury. The goal was to model the emission, transport, and fate of airborne mercury over the continental U.S. for the year of 1989. Modifications to RELMAP for atmospheric mercury simulation were largely based on recent Lagrangian model developments in Europe (Petersen et al. 1994). The mercury version of RELMAP was developed to handle three species of mercury--elemental (Hg^0), divalent (the mercuric ion, Hg^{++}), and particulate Hg (Hg_{part})--and carbon soot. Recent experimental work indicates that both ozone (Munthe 1992) and carbon soot (Iverfeldt 1991, Brosset and Lord 1991, Lindqvist et al. 1991) are important in determining the wet deposition of Hg^0. Carbon soot, or total carbon aerosol, was included as a modeled pollutant in the mercury version of RELMAP to provide necessary information for the Hg^0 wet deposition parameterization. Observed O_3 air concentration data is used directly, and not explicitly modeled. Methyl mercury was not included in the mercury version of RELMAP because it is not yet known if it has a primary natural or anthropogenic source, or if it is produced in the atmosphere.

Major Questions

Vertical model domain. The RELMAP model top is defined to be the maximum vertical extent of the convectively driven mixed layer. Monthly values defined from mixed-layer-height climatology are rough estimates of a meteorological phenomenon that may not exist in many situations. Although a surface-based mixed layer may be well defined, pollutants that persist in the atmosphere for long periods of time are certain to mix to some degree into the free atmosphere above the mixed-layer top. Elemental mercury deposits relatively slowly through precipitation processes due to its low water solubility, and its dry deposition appears to be minimal since it is in vapor form under normal atmospheric conditions. Elemental mercury does appear to be quite persistent in the atmosphere.

Because RELMAP does not simulate the flux of air or pollutant through the height of the mixed layer, which is fixed for each monthly simulation, the use of horizontally divergent/convergent wind fields to define the motion of the pollutant puffs can sometimes result in unrealistic instantaneous concentration fields. RELMAP was not designed to provide instantaneous realizations of pollutant concentration fields. Rather, it was designed for seasonal and annual simulations where the total effects of convergent and divergent wind fields can balance one another. There is, however, some uncertainty as to whether this balance actually occurs in all situations.

Aqueous chemistry. The aqueous reduction-oxidation chemistry mechanism in the mercury version of RELMAP is applied only to the Hg^0 dissolved from the ambient air into the water droplet. Where significant concentrations of Hg^{++} from emissions exist in the ambient air, this Hg^{++} could be dissolved into the water droplet along with the Hg^0 and inhibit the scavenging of Hg^0. RELMAP simulation results described above indicate that Hg^{++} air concentrations are certainly lower than those for Hg^0 at the length scales of the RELMAP grid cells. However, the magnitude of the effect of ambient Hg^{++} on the Hg^0 oxidation scavenging is not yet well understood.

Another source of modeling uncertainty in aqueous chemistry relates to the fact that the aqueous chemical mechanisms were invoked only when and where precipitation was known to occur, and precipitation fields were only defined over land areas where precipitation observations were available. Significant wet transformation and removal of mercury may occur over oceanic areas were precipitation observations are not available, and it is possible that significant aqueous chemistry is occurring in non-precipitating clouds.

Transport and diffusion. RELMAP simulates transport and diffusion only in the surface-based mixed layer. Vertical wind shear is small when the mixed-layer is well defined, so under ideal conditions transport and diffusion are handled adequately. When the surface-based mixed layer is not well defined, however, vertical gradients in the speed and/or direction of the wind may be present. These cannot be represented by the motion of individual Lagrangian puffs whose layers remain vertically stacked. The most complete solution to the problem of vertical wind shear is the use of an Eulerian reference frame for numerical modeling. The Atmospheric Characterization and

Modeling Division of EPA's Atmospheric Research and Exposure Assessment Laboratory has proposed the development of a Toxics Linear Chemistry Model (TLCM) using the Eulerian reference frame of the Regional Acid Deposition Model (RADM). Were this initiative to be adequately supported, the TLCM could be operational within two years.

Boundary fluxes of pollutants. Due to the RELMAP treatment of atmospheric pollutant loading as the combined effects of a population of discrete Lagrangian puffs, and the long residence time of elemental mercury gas in the atmosphere, natural mercury emissions from the oceans and land surfaces cannot be explicitly modeled. The use of an Eulerian-type model would allow the definition of boundary fluxes of pollutant based on larger-scale model results or assumed background concentration levels.

Current Research

Development of Eulerian model. The Atmospheric Characterization and Modeling Division of EPA's Atmospheric Research and Exposure Assessment Laboratory has proposed the development of a long range atmospheric transport and transformation model using the Eulerian reference frame of the Regional Acid Deposition Model (RADM). This model will include internal nesting so that subregions can be examined in detail within a framework that provides boundary concentrations from long-range transport. Given adequate support, two years would suffice to make this model operational.

Application of Eulerian model to South Florida. The Eulerian atmospheric transport model will be modified for mercury constituents and applied to the South Florida region. Vapor concentration and deposition data will be provided at a set of atmospheric monitoring stations covering eastern, central, and western South Florida. An inventory of mercury sources will provide the loadings to the model. A series of calibration simulations will cover the period of data collection, and will focus on uncertain processes and model parameters. Following calibration, another series of simulations will be conducted to predict long-term atmospheric mercury trends given various management options.

Research Needs

The proper application of an environmental fate model requires the specification of input data that describe and parameterize the environment being investigated. Data needs are discussed below.

Emissions inventory. Loadings of mercury introduced to the atmosphere from various sources, including coal-fired utilities, municipal waste incinerators, and medical waste incinerators, must be quantified and characterized. Knowledge of the oxidative state and physical form of the emitted mercury is important because these properties can influence the pattern of atmospheric dispersion and deposition. Knowledge of loadings of elemental, mercuric, and methyl mercury are desired. EPA/ORD/AREAL believes that there is presently no adequate method for analyzing the species of mercury in emissions, and further that current stack sampling methods do not adequately characterize the chemical and physical form of mercury emissions as they manifest themselves on the regional scale. Chemical and physical transformations appear to be occurring in the exhaust flue and/or the local plume which create a discrepancy between the mercury constituents measured in the stack and those measured in the atmosphere.

Wet and dry deposition fluxes. A spatial and temporal description of depositional loadings of elemental, mercuric, and methyl mercury is needed to drive aquatic fate models. While wet and dry fluxes may be measured at selected locations, a regional airshed model with local sources should be used with the observed data to more precisely understand the loading patterns and to distinguish among various local sources and regional and global background sources.

Mercury vapor concentrations and exchange rates. Elemental mercury in the air may undergo volatile exchange with concentrations in soil and water. This may provide a net source or sink to the ecosystem. Vapor concentrations in the air should be measured at selected monitoring locations. In addition, mercury vapor transport and reactions

should be included in a regional airshed model. Experiments to quantify volatile exchange rates should be undertaken.

Mercury plume chemistry. Physical and chemical reactions affecting mercury speciation in the plume must be described and quantified. These reactions are expected to affect the amount of mercury that is deposited locally in wetfall, and the concentration of elemental mercury vapor that may exchange with the watershed. They may also help to explain the discrepancies in the chemical and physical form of mercury that often appear between stack gas measurements and ambient atmospheric measurements.

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ENDANGERED AND THREATENED SPECIES

INTRODUCTION

The large number of endangered and threatened species within the south Florida ecosystem reflects the substantial direct loss of habitat and the alteration of ecological processes of the remaining system. Patterns and quality of water flow through wetlands have been altered and water tables have been lowered under remaining upland habitat. Fifty-four plant and 51 animal species within the region are listed or candidates for listing under the federal endangered species act. Additional species are listed by the Florida Game and Freshwater Fish Commission, Florida Natural Areas Inventory, and Florida Committee on Rare and Endangered Biota, as rare, threatened or endangered. Revised species accounts prepared by the FCREPA are now being published in a series of volumes, "Rare and Endangered Biota of Florida" (for example see Humphrey 1992, Molar 1992). This assessment prepared for the Science Sub-group deals with the research needs of those species or populations that are federally listed as either endangered or threatened. Our assignment was to review those species occurring in the southern half of the Everglades basin, and thus, for the most part, our comments pertain to subregions 4-9.

The National Audubon Society convened an independent panel of scientists to considered the challenge of recovering endangered species in the Everglades within the framework of a regional restoration program (Orians et al. 1992). This panel concluded that with proper planning, and with improved endangered species monitoring protocols, it should be feasible to move forward with restoration while maintaining or improving the status of populations of endangered species. The panel concluded that for wetland dependent endangered species, restoration may be the best option for achieving recovery of these species. The panel further articulated the need for a comprehensive multi-species recovery plan for this area and for reassessment of critical habitats for each of the species.

Endangered and threatened species within the south Florida ecosystem can be classified into two broad groups. The first are those wetland dependent species for which restoration of natural hydropatterns and the quality of water within the system should improve the habitat for these species. The other group includes terrestrial species which may or may not benefit from restoration of freshwater conditions. These include species found in the uplands of the Florida Keys, pinelands and hardwood hammocks throughout the region, and the coastal ridges. The status of these species is determined by the amount, fragmentation and isolation of the remaining habitat (Robertson and Frederick 1994). Recovery of these species will, in many cases, depend on some interplay between the affects of habitat fragmentation, fire management practices, and the extent of exotic invasions.

In the development of restoration plans for south Florida wetlands, we have hypothesized that wetland dependent species will benefit, or at least will not experience adverse affects, from properly executed restoration. Close monitoring will be required to insure that these wetland species do not become extinct or further stressed as the system shifts from its current altered state to a more restored condition. Sequencing of the restoration efforts through some adaptive management process may be necessary to insure the protection of some of these species. This raises a question of possible adverse impacts that hydrological restoration may have on terrestrial dependent endangered species. Is it possible that species such as the Florida Panther may have less habitat available following restoration?

REGIONAL RECOMMENDATIONS

At least five key components need to be included in monitoring and research plans for all listed species. (1). Conduct censuses of breeding and wintering populations of all species at regular intervals throughout the Everglades basin. Censusing protocols must be repeatable, statistically sound, and standardized across the region. New census protocols must be developed for some species. (2). Develop ecological studies that address critical management questions for each of the species. These data will be essential for the development of restoration plans in a manner

that insures the improvement of the status of the species within the system. (3). Undertake a population viability analysis for each species to help identify bottlenecks in the life cycle of each species which must be addressed during restoration planning. (4). Evaluate the status of state-listed species, and other species or populations not currently federally listed, but which may be threatened with extirpation in the Everglades basin. Develop priorities for research and monitoring from this expanded list of species of regional concern. (5). Append to restoration plans a multi-species recovery plan, which identifies potential conflicts between species recovery plans and restoration plans, and describes protocols for addressing these conflicts.

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TAXONOMIC SUMMARIES

Plants

The number of Florida plants thought to need special conservation measures has grown rapidly in recent years. As of 7 September 1993 (Wood 1993), 567 taxa, roughly 15 percent of the state's native flora, were listed as "Endangered" or "Threatened" (or as candidates for such status) by agencies of the State of Florida or by the USFWS. The above figure is more than 3 times the number of species treated by Ward (1978) in the "Plants" volume of "Rare and Endangered Biota of Florida". It appears that approximately 55 percent of the combined state- and federal-listed plant species occur or once occurred within areas that may be affected, at least marginally, by Everglades restoration. This estimate includes the listed plants found only in the Florida Keys.

Nine plant species, 7 endangered and 2 threatened, have been listed or proposed for listing by the USFWS within the Everglades restoration area. Two of these, the endangered Okeechobee gourd (Cucurbita okeechobeensis) and the threatened climbing dayflower (Commelina gigas), are plants of wetlands of Lake Okeechobee and the northern Everglades. The effects on individuals and habitat of these species would need to be considered and mitigated, wherever they are present in areas to be modified by restoration. The remaining federally-listed plants are: Miami lead plant, Amorpha crenulata; Small's milkpea, Galactia smallii; tiny milkwort, Polygala smallii; the threatened Garber's spurge, Chamaesyce garberi; tree cactus, Cereus robinii; pineland clustervine, Jacquemontia curtisii; and, beach clustervine, Jacquemontia reclinata. All are plants of upland areas (principally pine rocklands) and beaches not likely to be altered by restoration activities. The major enclave of rare wetland plants (but no current federally-listed species) within the restoration area is the Fakahatchee Strand in southern Collier County. Ponds and swamp forests in this area harbor about 25 species of epiphytic ferns, orchids, and bromeliads not found elsewhere in the U.S. Major hydrological changes in the Fakahatchee Strand during restoration should be avoided.

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Reptiles and Amphibians

I. Major Issues: The federal list of endangered and threatened reptiles, which are known to occur in one or more of the central and southern subregions of the Everglades basin, consists of five species of sea turtles (green, leatherback, loggerhead, hawksbill & Kemp's ridley), the American crocodile, and the Eastern indigo snake. No federally listed species of amphibian occurs in these subregions. Ecosystem restoration in the Everglades basin should benefit these regional populations, or at worst should have no negative impacts. In order to assure that this goal is achieved, restoration planning must be based on adequate information on the ecology and distribution of these populations within the region.

II. Background: Of the five species of sea turtles, two are known to nest regularly on beaches in one or more of the subregions. The loggerhead is a locally common nester on both Atlantic and Gulf coast beaches, including Cape Sable and the Dry Tortugas (Davis and Whiting 1977, Williams and Dawson 1984), and the green turtle nests in limited, but perhaps increasing numbers along the central and southern Atlantic coast (Conley and Hoffman 1987; the leatherback and hawksbill also may nest rarely at sites on the ocean side of the keys). The loggerhead, green and hawksbill regularly use seagrass beds, tidal channels and reef tracks and patches as feeding habitat, including grass beds and channels in Florida Bay. The other two species, leatherback and Kemp's ridley, are of very rare and uncertain status in the region. Population trends by the nesting species are unknown because no long-term nest monitoring programs for all of the important nesting beaches in the region have been maintained.

Sea turtles once were much more common in southern Florida estuaries, as is indicated by the prevalence of a commercial sea turtle fishery in these waters between the 1850s and 1973 (Rebel 1974). The impacts that degradation in sea grass beds and coral reef communities have had on these turtles remains unknown, in large part because of difficulties in estimating current populations and seasonal patterns from existing data. The continuing importance of these habitats, however, is suggested by a sample of sea turtles captured for tagging on banks in western Florida Bay in 1990 and 1991, which consisted of 51 loggerheads, 23 greens and one hawksbill (mostly subadults; S. Snow pers. comm.). Hawksbills are more common around reefs and ocean creeks in Biscayne and Fort Jefferson National Parks (Robertson 1989a).

The American crocodile has disappeared from most of its former range in Biscayne Bay and the Florida Keys, and has retained viable nesting sub-populations only in eastern and northern Florida Bay as far west as the Cape Sable peninsula, on northern Key Largo, and in the Turkey Point cooling canals (Ogden 1978, Kushlan and Mazzotti 1989a). Mazzotti (1994) has shown that although the number of nesting female crocodiles in Everglades National Park has been stable or slowing increasing during the past decade, the number nesting in traditional creek habitats in northeastern Florida Bay has declined. It is not known whether the decline in the number of creek nests is due to some as yet undiscovered environmental change that has occurred in this area (Mazzotti and Brandt 1989). Although the crocodile is the best studied and monitored of the listed species of reptiles in the region (Kushlan and Mazzotti 1989b, Mazzotti 1989, Moler 1991), the fact that a major segment of the nesting population occurs downstream from the degraded Taylor Slough/C-111 basins, and that relationships between crocodile distribution and salinity remain poorly known, demands that close attention be given to this species during the restoration process.

Although the indigo snake remains widespread in pinelands and hammocks throughout southern Florida, little is known of population trends (Steiner et al. 1983, Dalrymple 1988, Robertson 1989b). Subpopulations are expected to remain secure on well protected, public lands, but may decline where habitat alteration and collecting can occur.

III. Spatial aspects: The sea turtles are restricted to coastal beaches, broad bays and lagoons and offshore areas, while the crocodile is an estuarine species associated with undisturbed tracts of mangrove and lagoon habitats. The indigo snake is essentially an upland species throughout the region.

IV. Current Research: Except for sea turtle nest monitoring projects on several public beaches in south Florida, conducted largely by volunteers, no organized research or monitoring for sea turtles is presently in place. Most known crocodile nests at Turkey Point, northern Key Largo, and in Everglades National Park, are monitored annually for measures of activity and success. No current studies of indigo snake are known.

V. Research objectives:

A. Determine relationships between crocodile distribution, nesting patterns and success, survival of age classes, and salinity.

B. Continue and expand long-term monitoring program for crocodile nesting in south Florida.

C. Implement nesting censuses for sea turtles using standard sea turtle nest census protocols, on beaches in Everglades and Ft. Jefferson National Parks and elsewhere as required, to compare with earlier nesting studies.

D. Determine condition and relative importance of sea turtle feeding habitats in Florida Bay and in waters adjacent to the upper Florida Keys, and develop a GIS model of juvenile habitats.

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Birds

I. Major Issues: The federal list of birds includes seven endangered species, two threatened and five candidate species. Restoration of pre-drainage patterns of freshwater flow from Lake Okeechobee south through the Everglades to the estuaries should benefit two endangered species (wood stork, snail kite), but will have uncertain affects on two other endangered species (Cape Sable sparrow, and bald eagle), and on two candidate species (mangrove clapper rail, reddish egret). Proper management of old growth pine forests within the region probably will have the greatest benefit for the red-cockaded woodpecker (Endangered) and Southeastern kestrel (candidate). Conversion of wetlands into citrus groves represent a serious threat to all freshwater, endangered species. Southeastern snowy plovers (candidate) winter along sandy beaches within the region, and peregrine falcon (Endangered) migrate through the entire region and winter in coastal areas. Protection of tropical upland forests on the mainland and in the Florida Keys is the largest factor influencing the status of white-crowned pigeon (candidate).

A suite of additional species of birds are listed by the Florida Game and Freshwater Fish Commission, Florida Natural Areas Inventory, and Florida Committee on Rare and Endangered Biota. The state lists include a number of wetland species that are dependent on freshwater and estuarine habitats that are likely to be directly influenced by hydrologic restoration.

Cape Sable seaside sparrow (Endangered)

Cape Sable seaside sparrows occur in freshwater prairies bordering the southern Everglades (Werner 1976, Bass and Kushlan 1982, Curnutt and Pimm 1993). The Cape Sable sparrow populations on Cape Sable and in the Ochopee region have been greatly reduced or extirpated apparently because of habitat alterations. Currently most of the population is divided between the east and west flanks of Shark Slough and across the high elevation marshes bordering the upper Taylor Slough region. Kushlan et al (1982) summarized current knowledge of the spatial relations, movement, and breeding biology of Cape Sable seaside sparrows. These sparrows nest in discreet subpopulations that are patchily distributed across short-hydroperiod marshes. Although the distribution and density of nesting birds are affected by the patterns and seasonality of water coverage and by the frequencies and distribution of fires, these relationships have been only superficially measured.

Research objectives:

A. A better definition of the habitat requirements in terms of fire frequency and hydrology needs to be developed for this species in both the Taylor Slough and southern Big Cypress basin. Annual censuses of the distribution and density of the sparrows, relative to fire and water conditions, are required.

B. It is critical that the dispersal and colonization ability of both adult and young sparrows be well understood. Radio-telemetry studies of adults and young should be undertaken to determine movement patterns of individual birds.

C. Improvement in the understanding of habitat requirements and the reasons for patchy distribution is necessary for the development of restoration plans that will maintain this species as hydrological conditions are changing during the restoration process.

D. Detailed color-marking study of one colony needs to be undertaken to determine aspects of demography such as dispersal patterns relative to age and sex, survivorship, and effects of fire on distribution.

Snail kite (Endangered)

The snail kite population in Florida currently numbers between 700 and 1,000 individuals (R. Bennetts pers. comm.). Annual censuses have been conducted since the late 1960s, providing a relatively long record of population changes (Rodgers et al. 1988). The current number represents a recovery from a population that may have been as low of a few dozen birds during the late 1950s and early 1960s. R. Bennetts is currently investigating several aspects of snail kite biology that are crucially important to restoration planning, including relationships between kite dispersal and reproductive patterns, and water depth and drying patterns, and the affects of dispersal on mortality and reproductive patterns. This study, now in its fourth year and faced with funding cuts, is showing that kites have greater than expected dispersal and survival rates, and wider habitat tolerances, than were previously suspected (Beissinger and Takekawa 1983, Beissinger 1988, Bennetts et al. 1988, Bennetts et al. 1994). The current study by Bennetts also will describe an improved census protocol for snail kites that will measure kite population trends more accurately than has been possible with past censuses.

Although snail kites feed almost exclusively on apple snails, the environmental dynamics of snail populations are only poorly understood, in large part because of difficulties in measuring snail numbers, densities and survival patterns.

Research objectives:

A. Continue detailed ecological studies of the response of kites to changing water conditions within south Florida, to take advantage of the large number of birds currently carrying functional radio transmitters. Maintain monitoring and reproductive studies of breeding populations of snail kites throughout their Florida range.

B. Develop an study of the ecology of apple snails and what conditions make them available to snail kites.

C. Implement an improved kite censusing program that more accurately estimates populations of kites.

Wood storks (Endangered)

Wood storks are highly social birds, nesting in colonies and feeding in flocks. Historically, between 2,500 and 4,000 pairs nested in large colonies in Everglades National Park, and as many as 10,000 pairs nested in the Big Cypress region (Ogden 1994). Numbers nesting in these two regions have greatly declined, primarily since the early 1960s, to less than 100 pair in Everglades National Park, and less than 500 pairs in Big Cypress colonies. A major factor responsible for the population decline has been a substantial delay in the timing of nesting that has occurred since the 1960s and in both Everglades and cypress colonies, and which has resulted in a sharp decline in nesting success. Delayed nesting is thought to have been caused by losses in foraging habitat during the early and mid-dry seasons, which have forced birds to delay nesting until the deeper, central sloughs dry during the late dry season. It has been hypothesized that those critical, early dry season foraging habitats were either (or both) the higher elevation, freshwater marl prairies that flank the deeper sloughs, or the broad, mainland estuaries bordering northern Florida Bay and the southwestern Gulf coast (Robertson and Frederick

1994). Hydrological mechanisms that may have reduced the production, survival and availability of fishes as prey (Ogden et al. 1976) for storks in these two habitats have not been measured.

Historically, south Florida was the most important nesting area for the southeastern United States population of wood storks (Ogden and Nesbitt 1979, Ogden et al. 1987). This region is no longer important as a nesting area for this species but still remains extremely important as a winter and spring foraging area for birds that subsequently migrate north (Bancroft et al. 1993). Breeding storks have responded to the deterioration of the Everglades/Big Cypress region by shifting colony locations into north Florida, Georgia and South Carolina.

Research objectives:

A. A detailed demographic study of storks nesting in the Everglades basin needs to be undertaken with the aim of better quantifying aspects of recruitment, and adult and juvenile survivorship related to late nesting.

B. A detailed study of the effects of mercury, other toxins, and parasites on the survivorship and reproductive success of wood storks.

C. Analysis of the factors that determine when and where Wood Storks forage and nest. The Systematic Reconnaissance Study data set in combination with colony and historical survey data should be used to look at the relationships between timing and location of colonies and regional hydrological patterns. An important part of this study would be to document what appear to be changing relationships between stork nesting patterns and regional hydropatterns which presumably reflect fundamental changes in the way the Everglades system operates at primary and secondary production levels.

Southern bald eagle (Endangered)

In Florida, bald eagles nest in riparian, lake and coastal areas. Eagles feed on a wide variety of vertebrate prey, primarily fish, but including birds and turtles (Robertson 1989a). Eagles generally initiate nesting in October to November and young fledge in mid to late spring. Many individuals, especially young, disperse north during the summer. Pairs are permanently territorial and often will repeatedly use the same nest for a number of years. Reasons why the breeding population of eagles in Florida Bay has been relatively stable since the 1950s (Robertson, pers comm.), while the osprey (also fish eaters) population in the Bay has declined, are not known.

Research objectives:

A. A detailed monitoring and research program is required to look at the distribution and possible impacts of mercury on bald eagles.

B. Radio-tracking and/or satellite tracking of juvenile and adult eagles nesting in Everglades National Park and the Florida Keys needs to be undertaken to determine annual movement patterns related to habitat requirements, especially during non-breeding periods.

C. Continue, and expand as needed, monitoring of nesting bald eagles throughout Everglades National Park, the Big Cypress region and the Florida Keys.

Red-cockaded woodpecker (Endangered)

In Florida, red-cockaded woodpeckers occur as scattered populations in mature pinelands, throughout the peninsula as far south as the southern Big Cypress region, and formally in the Long Pine Key pinelands of Everglades National Park (Robertson 1989b). This species excavates nesting and roosting cavities only in older, living pines. Generally these trees are only available in old growth stands. Local populations maintain cohesive social groups, which operate as discreet units, resident units throughout the year. Each "clan" maintains several cavity trees; each cavity tree may require more than one year to fully excavate (Baker 1971). Red-cockaded woodpeckers disappeared from the pinelands of southern Dade County between 1935-1965, including those in Everglades National Park, associated with logging and urban/agricultural development (Robertson 1989). Although the small colonies in the Big Cypress continue to survive, the numbers of birds has been slowly declining; additionally, some cavity trees in the southern Big Cypress were damaged by Hurricane Andrew (D. Jansen, pers. comm.). The major conservation issues for this woodpecker in southern Florida are (1) the status and preservation of the Big Cypress population, and (2) the possibility of re-introducing the species into pine forests of Long Pine Key, Everglades National Park.

Research objectives:

A. An expanded ecological and distributional survey of the Big Cypress population is required. Distributional surveys of clans within Big Cypress Preserve and the addition area needs to be completed and maintained. Survey area should be expanded to include surrounding pinelands not in federal ownership that may contain woodpeckers or could have them reintroduced.

B. Ecological studies of the Big Cypress population to better measure habitat requirements, survivorship, dispersal capabilities, movement patterns and population viability.

C. Survey of areas where red-cockaded woodpeckers may be able to be reintroduced, including Long Pine Key, Everglades National Park.

White-crowned pigeon (C2 candidate species)

In the United States, the white-crowned pigeon occurs primarily from the southern tip of the Florida peninsula south through the Florida Keys. This tropical pigeon is most abundant from May through September when it breeds on mangrove keys from Biscayne Bay south. Major nesting concentrations occur in Florida Bay and in the Great White Heron and Key Deer National Wildlife Refuges (Bancroft et al. 1994). Nesting distribution appears limited by the presence of raccoons and other nest predators. Pigeons make daily flights to tropical hardwood forests to feed (Strong et al. 1994). During the breeding season, they feed primarily on the fruits of poisonwood, blolly, short-leaf fig, strangler fig, and black torch. Within the United States the greatest threat to this species is the continued destruction of tropical hardwood forests. The expansion of raccoons and disturbance of birds on the nesting islands by humans continues to decrease the availability of safe nesting areas. Most white-crowned pigeons from Florida winter in the Bahamas or the Greater Antilles. Little is known about the wintering ecology or migratory behavior of white-crowned pigeons from Florida.

Research objectives:

A. Purchase and protect all remaining tropical forest parcels larger than 5 ha from Key Largo south to Key West. Complete North Key Largo, Tropical Flyways, Big Pine/Coupon Bight, and Lower Keys Hammocks project on the Conservation and Recreational Lands Program. Finish federal acquisition of lands in Crocodile Lakes and Key Deer National Wildlife Refuges.

B. Conduct comprehensive censuses of pigeon nesting and feeding habitats in the lower Florida keys.

II. Current Avian Research: J. Curnutt and S. Pimm, University of Tennessee, are investigating relationships between Cape Sable sparrow populations and hydrological and burning patterns in the marshes. Annual censuses of the total Cape Sable sparrow population have been conducted 1992-1994, by Everglades National Park. R. Bennetts is in the forth year of a study of snail kite population dynamics related to hydrological variables, the details of which are described under the snail kite heading. Except for annual censuses of nesting colonies, no wood stork studies are currently active. Bald eagle nests in Florida Bay and along the Gulf coast of Everglades National Park are monitored annually by W. Robertson, N.B.S. Reports on red-cockaded woodpecker censuses (D. Jansen) and research (K. Meyer) in the Big Cypress National Preserve are now in preparation. No white-crowned pigeon projects are currently active.

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Mammals

I. Major Issues: Seven species of mammals that are federally listed as endangered or threatened occur in the central/southern subregions of the Everglades basin (Florida panther, key deer, Key Largo cotton mouse, Key Largo woodrat, lower keys marsh rabbit, silver rice rat, and West Indian manatee). It is possible that restoration of Everglades wetlands may adversely impact the panther by reducing the total area of habitat suitable to panthers or their primary natural prey (white-tailed deer), and by further isolating any remaining animals in the subpopulation that may still occur east of Shark Slough. It is not suspected that ecosystem restoration will have a major affect on manatee, although reduced salinities in south Florida estuaries may create better foraging habitat conditions.

II. Background: Five of the seven listed species in this region are restricted to the Florida Keys; the continued survival or recovery of these keys populations will depend on preservation of adequate amounts of upland habitats (key deer, cotton mouse, woodrat), and for two lower keys species (marsh rabbit, rice rat), adequate wetland habitats.

The strongest population trend database for manatee from the southern Everglades subregions is based on aerial censuses conducted along the Gulf coast estuaries and in Florida Bay, of Everglades National Park, in a number of years between 1973 and 1993 (Beeler and O'Shea 1988, Snow 1993). Although these censuses showed the

highest total numbers were in 1991 (1451) and 1992 (1585), relative declines occurred in two areas where salinities may have increased as a result of reduced flows from the Everglades (Whitewater Bay and northern Florida Bay). These censuses seem to support the preliminary conclusion that "to some degree" movements and aggregations of manatees can be correlated with the distribution of seagrasses and vascular freshwater aquatic vegetation (Hartman 1974). However, the relationships between manatees and aquatic vegetation and salinity patterns remain poorly understood. The censuses also show seasonal patterns of movements and distribution that have yet to explained by environmental correlations. Many other aspects of the biology and ecology of manatee in southern Florida have not been studied.

The Florida panther has been much more intensively studied than any other endangered mammal in southern Florida (McBride 1985, U.S. Fish and Wildlife Service 1987, Belden 1988, Alvarez 1993, Smith and Bass 1994). These reports show that although upland forests are the preferred panther habitat in southern Florida, animals often include large areas of aquatic habitats within hunting ranges. However, extensive wetlands may limit panther movements, as has been suggested by observations that panthers are more likely to cross Shark Slough during extended dry periods (O. Bass pers. comm.). In addition, white-tailed deer, an important prey species for panther, also tend to move out of Everglades marshes during periods of deeper flooding (Fleming 1991). These observations suggest that water depth and distribution patterns may influence panther distribution patterns, either directly or by affecting prey patterns. However, in spite of the number of studies on panther in southern Florida, relationships between prey abundance and distribution, and hydrological parameters, are either poorly known or poorly reported.

III. Spatial aspects: Of the two mainland species, the panther occurs throughout the Big Cypress and freshwater portions of the western Everglades, primarily in upland woodlands, while the manatee is primarily coastal (also in canals and rarely into Lake Okeechobee).

IV. Current Research: Except for monitoring of panther, primarily in the Big Cypress subregion, and annual, state-coordinated manatee censuses, no mammal studies are known.

V. Research objectives:

A. Continue long-term censuses of manatee, to measure distribution and abundance.

B. Develop benthic vegetation maps for Everglades National Park, for the interpretation of manatee movement/distribution patterns.

C. Determine the ecological and physiological freshwater requirements of the manatee. Use telemetry to address movement patterns related to hydrological parameters.

D. Analyze existing food habits data for the panther, relative to the effects that hydrological patterns have on the distribution and abundance of prey species.

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HARMFUL NON-INDIGENOUS PLANTS AND ANIMALS

INTRODUCTION

Non-indigenous species are those that are not native to a specific area but were introduced anthropogenically. They are sometimes referred to as non-native species or exotic species. Some of these species are also referred to as pest, nuisance, harmful, or invasive species.

Invasion by non-indigenous plant species originating from throughout the tropical-subtropical world is a major factor threatening south Florida natural areas. Many nonindigenous plant and animal species have escaped cultivation and become established in south Florida. Some have not only colonized disturbed sites, but also invaded natural lands that have been set aside for preservation of natural communities and landscapes. South Florida probably has more problems with aggressive non-indigenous species than any other state. The state as a whole has approximately 925 established non-indigenous plant species growing outside of cultivation (OTA 1993). Over 100 of these are listed as invasive in Florida by the Exotic Pest Plant Council (EPPC) (1993). Melaleuca and Brazilian pepper are better known examples of harmful non-indigenous trees that are widespread and increasing in South Florida. At least 23 non-indigenous plants now are found in Florida's waters (McCann et al. 1994). Non-indigenous plants and land animals constitute about 25 percent of all species in the state (OTA 1993).

Many non-indigenous animal species have become established in Florida's aquatic systems: 83 fish, at least 26 insects since 1970, 2 amphibians, 3 birds, 1 mammal, 1 reptile, 5 mollusks, 1 crustacea and an unknown number of pathogens (McCann et al. 1994). Many non-indigenous terrestrial animals, particularly birds, reptiles, and amphibians, have escaped captivity and are reproducing in south Florida. Sixty-three percent of the introduced non-indigenous bird species in the continental U.S. are found in Florida, which also has the largest number of established non-indigenous amphibians and reptile species in the U.S. (OTA 1993).

MAJOR ISSUES/PROBLEMS

Scientific research on exotic species in Florida has been underfunded, considering the magnitude of the problem and the potential for further damage to the ecosystem. Most resources have been focused on agricultural pests and aquatic weeds. Little has been spent on research concerning exotic species that are a threat to natural areas. Two types of research are needed: (1) research to develop technology and (2) basic biological and ecological research to improve understanding of invasive exotic species. With respect to technology development, research needs include biological control, screening and risk assessment, habitat restoration strategies, and propagation of sterile species. Ecological research should be undertaken to develop greater understanding and perspective on the problem. Both types of research are vitally important to the South Florida Ecosystem Restoration effort. Inadequacies in the intensity and breadth of research are the major issues.

Biological control research, although it has made promising progress, is inadequately funded, and other eradication methods alone cannot control region-wide invasions. A serious concern is that the quarantine facility at Ft. Lauderdale, which is a component of a biological control research program, is not yet fully funded.

Scientifically based screening and risk assessment methods are lacking, but are needed to prioritize species so that the greatest threats receive the most attention. Screening and risk assessment should be used at several points in the control process: restricting importations; influencing propagation, distribution, and planting; and eradication of infestations.

Habitat restoration strategies are needed to prevent invasive non-indigenous plants from returning, once they are removed from heavily infested areas. One general strategy is to replant native vegetation, but scientifically supported guidelines on how to reestablish native plant communities most effectively are limited for south Florida.

The limited amount of biological and ecological information concerning invasive species affects the ability to generate funding or devise control strategies. Research is needed to address the following questions:

What affects will water management alterations for purposes of ecologic restoration have on non-indigenous plants and animals?

What are the impacts on native species and natural areas of infestation with non-native species?

What ecological roles do non-native animals play in the natural habitats in which they are found?

What are the major factors influencing expansion rates of specific problem species in south Florida?

What factors make a natural area site susceptible to invasion by non-natives?

What are autecological aspects of various problem species, including phenology and response to environmental variables, that might allow them to be controlled by management measures such as adoption of new water management or control burning practices?

How do non-indigenous plant species that establish monocultures affect the water budget? For instance, does melaleuca consume more water, particularly during the dry season, than the native species it replaces?

BACKGROUND

Description of the Problem

Non-indigenous plants negatively impact native habitats by outcompeting natives, decreasing species diversity and altering topography and soils. Nuisance plants significantly reduce available native habitat for several Federal Endangered Species. Dense monocultures formed by melaleuca replace native vegetation which can decrease nesting and foraging habitats for endangered species like the snail kite and Cape Sable seaside sparrow.

Aquatic plants such as hydrilla, water lettuce, and water hyacinth clog streams, rivers and lakes. Aquatic weeds create a continual problem by obstructing navigable waterways throughout the Kissimmee-Okeechobee-Everglades system. Millions of dollars and extensive labor are spent each year to reduce the impediment caused by aquatic weeds. Herbicides are frequently used to prevent waterways and lakes from water ways. Therefore prolific nonindigenous plants are indirectly responsible for the application of tons of chemicals to state waters.

Prolific animal species that have escaped to the wild may degrade the quality of habitat for native wildlife, introduce diseases or pathogens, or outcompete or prey on native species. In many locations non-native herpetofauna such as *Anoles segrii* have replaced native congenitors such as *Anoles carolinensis*.

Not all non-indigenous species are harmful. Many nonindigenous plant species never escape cultivation. Not even all that spread beyond their planting site are invasive. In south Florida, however, the potential for harm to natural areas from even one invasive plant species is enormous. For instance, *Melaleuca quinquenervia*, which was introduced in the early 1900's, now infests roughly 450,000 acres of south Florida to some degree (OTA 1993). At least 50,000 to 60,000 of melaleuca are growing as a monoculture (R. Doren, Everglades National Park, pers.

comm.). Past experience and a rate of expansion study indicate that the uncontrolled trees could overtake most of the region's remaining natural land within 30 years (Bodle et al. 1994).

Melaleuca is just one example of the many species that are rapidly expanding in South Florida natural areas. A virtually uncontrolled expansion of non-indigenous species is altering the South Florida landscape and affecting the functioning and biological integrity of the ecosystem. A coordinated, integrated multispecies research program is needed to develop information and techniques to help control invasions by non-indigenous plants and animals that have already escaped cultivation and to prevent the introduction of new invaders.

Some Existing Efforts

A comprehensive review and analysis of the effort to control harmful non-indigenous species recently was published by the U.S. Congress Office of Technology Assessment (OTA) (1993). Many needed research topics can be gleaned from that document, which includes a special section on Florida.

The EPPC is a nongovernmental group formed in 1982 to address the dilemma of invasive non-indigenous plants in Florida. One major activity of this group has been to develop an extensive, prioritized list of harmful non-indigenous plants. The present list includes 126 problematic non-indigenous species. The EPPC has a research committee whose responsibilities are to determine research priorities and facilitate funding coalitions and review research proposals.

Considerable progress has been made in developing effective methods for eradication of melaleuca on a local scale, and these methods are being applied in a coordinated effort in parts of South Florida. A Melaleuca Task Force was formed by several concerned entities that have joined together to systematically eradicate melaleuca. Several control operations and methods are currently being researched and implemented by this group (Melaleuca Task Force 1994).

Many state agencies are involved in the control of exotics. The Florida Department of Environmental Protection and the U.S. Army Corps of Engineers contribute to and support numerous exotic removal programs. The South Florida Water Management District leads several exotic eradication efforts in South Florida. The Florida Department of Transportation continually reduces and maintains invasive non-indigenous plants on right of ways.

Federal agencies have ongoing eradication projects within the boundaries of national wildlife refuges and national parks and preserves. Local county Park and Recreation efforts have concentrated on removing invasive non-native plants from natural areas throughout the South Florida Region.

Local agencies also have exotic removal efforts. The Dade County Park and Recreation Department has a multimillion dollar exotic control program underway in tropical hammock areas to help the Park natural areas recover from invasions of non-indigenous plants and some prolific native vines after Hurricane Andrew.

Several federal laws deal with the importation of non-indigenous species. The Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 and the Lacey Act authorize the U. S. Fish and Wildlife Service to issue regulations on aquatic and other nuisance species and restrict importations of exotic species. The U.S. Department of Agriculture (APHIS) also has responsibilities under the Lacey Act and administers the Federal Noxious Weed Act of 1974 and the Federal Plant Pest Act. USDA responsibility includes the identification of actual or potential noxious weeds and preventing their entry into the United States (OTA 1993). These laws, as administered have not been effective in preventing the importation of non-indigenous species potentially harmful to natural ecosystems (OTA 1993).

Only a few groups are actively involved in research on non-indigenous species that threaten natural areas. Research activities that relate to both the management and the ecology of exotic species are conducted at Everglades National Park and the Big Cypress Preserve. The Park has conducted research on methods to restore natural

communities on rockplowed fallow farmland and prevent repeated reinvasions by non-indigenous species after their removal (Doren et al. 1990). The U.S. Army Corps of Engineers funds research relative to the control of aquatic weeds and melaleuca. The U.S. Department of Agriculture and the University of Florida are investigating various biological control organisms on several non-indigenous plants, including melaleuca and Brazilian pepper. Host-specific organisms are tested for their effectiveness as control agents and evidence for general safety. The introduction of host-specific insects, such as seed and sapling eaters, can safely and economically decrease the spreading of pest plants. Considerable progress has been made on the identification and testing of a biological control agent for melaleuca. At a proposed quarantine facility in Ft. Lauderdale, USDA plans to investigate the possible use of insects or plant pathogens to control or reverse the expansion of invasive nonindigenous plants, but the quarantine facility is not fully funded.

Recently a group was formed entitled the Federal Interdepartmental Committee for Management of Noxious Weeds. Many agencies within the Departments of Interior, Transportation, Energy, and Agriculture are involved. This group is responsible for coordinating noxious weed management. One of the group's objectives is to reorient the emphasis of control efforts toward protecting natural lands and rangelands, not just croplands. This may eventually lead to allocation of more research dollars to the protection of natural areas.

Publication of the OTA (1993) report on harmful non-indigenous species was a major step forward because it provides an overview of the problem and the present institutional framework for addressing the problem, as well as an evaluation of its effectiveness. A similar document specific to Florida is being prepared by The Florida Department of Environmental Protection. The National Park Service is planning a similar report for the Park Service.

RECOMMENDED APPROACH

- Prepare coordinated research programs on invasive or otherwise harmful non-indigenous species for inclusion in the separate multi-species management plans for plants and animals recommended in the Working Group Report (August 1993 draft).

The first step in the development of each research plan should be to provide a comprehensive review of recent and ongoing research. The planning and coordinating work of the EPPC should be brought into this process, and the experience and expertise from this group should be utilized in plan development. The programs should take a longterm view toward the problem of exotics in South Florida and should consider the problem in the context of the South Florida Restoration effort. Research should not be restricted to only studies of individual species, but rather should attempt to build a set of principles that helps support a holistic, ecosystem approach to exotics control. The questions listed in the major issues section above should be addressed.

- Continue and expand biological control research. (Suggested lead--USDA/ARS, ACE)

  This research must include:

  a. Foreign exploration - searching for most effective control species in the species' native land.
  b. Overseas screening process - determine most effective and safest species before importing to the U.S.
  c. Quarantine follow-up - clearance for field release.
  d. On-site field sites - colonization in areas affected.
  e. Assess the success and performance of introduced species.
  f. Technology transfer - distribute organism throughout range of species.

Provide funding for construction of, operation of, and support personnel for the quarantine facility at Fort Lauderdale and for improvement and maintenance of quarantine facilities in Gainesville. These are critical components of the biological control research program.

- Conduct research to develop an ecological understanding of invasive non-indigenous species. (Suggested lead--NBS)

With respect to plants, more work is needed on determining (1) factors that affect the invasibility of natural areas, (2) environmental requirements and phenology of particular problem species as these relate to their vulnerability to specific controlled burning or water management regimes, (3) common characteristics of invasive non-native species in Florida, (4) effects of non-indigenous plant infestations on native species and the environment, and (5) effective habitat restoration strategies to prevent reinvasion by non-indigenous species after their removal.

With respect to animals, research is needed on how non-indigenous species reproducing in the wild have impacted food webs, community structure, and populations of species in natural areas in which they have become established.

- Develop scientifically based methods for screening and risk assessment to prioritize efforts for controlling invasions at relatively early in the process (importation, distribution, colonization). (Suggested leads--USDA/ARS, NBS)

Effective criteria for identifying and screening potentially invasive or otherwise harmful non-indigenous plants and animals before they enter the country or before they become well established will help to focus preventive efforts. Research activities should be integrated with prevention and eradication efforts.

- Develop a multispecies monitoring plan. (Suggested Leads--NBS, FWS, NPS)

As part of plan development, existing monitoring programs should be inventoried and an analysis should be made to determine overlaps and gaps in coverage. The plan should ensure that basic variables are defined and measured the same way so that data can be analyzed across areas, not just locally. The activities of the COVER Group (Colloqui of Vegetation Everglades Research) should be supported and their efforts incorporated into the plan. A computerized atlas of ongoing monitoring programs should be prepared.

- Document the present nature and extent of invasion of south Florida's natural areas by non-native plant species and prepare a summary report. (Suggested Lead--NBS)

The survey might be approached through interviews with land managers, field biologists, and naturalists. In addition, limited areas should be selected, based on representativeness, sensitivity, or special concerns, for a quantitative analysis of plant invasions, including mapping. This activity should be coordinated with Florida DEP's current activities and with the COVER group.

- Prepare a prioritized list of non-indigenous plant species that are currently and potentially the greatest threat to natural areas. Suggest target areas and species for expanded control efforts.

Start with the list prepared by the EPPC. Use information from the recommended survey and available monitoring results. Develop information on a plant community basis (i.e., pineland, hammock, beach, etc.).

- Based on information from the above studies, generate brochures and news releases that describe the problem with non-indigenous species in South Florida to land managers, decision makers, and the public.

A public information effort based on scientific information will help develop a greater awareness of the problem and its present and potential impacts on natural areas. Once informed of their contributions to such problems, a concerned public often will change its habits.

- Conduct horticultural research to develop sterile cultivars of popular and widely used but invasive non-native ornamental plants, such as certain flowering trees and *Ficus* species. (Suggested Lead--Department of Agriculture)

This technology is being used elsewhere for esthetic reasons. Fruitless mulberry trees and podless locust trees are very popular nursery items in the southwestern United States. Developing sterile cultivars of non-natives with invasive tendencies should be an intensive activity that leads to quick results. Species such as royal poinciana, the orchid tree, surinam cherry, the exotic *Scaevola*, and the many ornamental *Ficus* trees would be good candidates for this treatment. Use the EPPC list to select non-native trees and shrubs whose propagation outside of cultivation should be controlled.

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SUBREGION 1:

KISSIMMEE RIVER BASIN

INTRODUCTION

This report presents a plan for the ecological monitoring and evaluation of the restoration of the Kissimmee River and several of its headwater lakes. That restoration is being conducted by the Corps of Engineers (Corps) and the South Florida Water Management District (SFWMD). The information and research strategies described are a compilation of studies in advanced stages of planning or early stages of implementation and do not represent a new research agenda. The research described was developed under the leadership of the SFWMD with input from the Corps, Florida Game and Freshwater Fish Commission (FGFWFC) and the U.S. Fish and Wildlife Service (FWS). In addition to ecological monitoring, hydraulic, sedimentation and structural stability monitoring will also occur; however, these are not the focus of this report and are discussed only briefly.

KISSIMMEE RIVER BASIN

The 2391 square mile Kissimmee River Basin begins south of Orlando and extends southward about 90 miles to Lake Okeechobee (Figure 1). The area is frequently divided into Upper and Lower Basins. The Upper Basin contains a series connected lakes, of which Lakes Tohopekaglia, Hatchineha, Cypress and Kissimmee are the largest. The Lower Basin contains Canal-38 and remnants of the Kissimmee River.

EXISTING CONDITION

The basin has been modified for navigation and flood control purposes since the 1890's; however, the most significant modifications occurred between 1962 and 1971 as a result of the Central and South Florida Flood Control Project which authorized Kissimmee River portion in 1954. That project established a regulation schedule for the Upper Basin lakes and created a 56 mile canal in place of the 103 mile Kissimmee River. Six structures in C-38 maintain water elevation, control water releases and provide lockage. The impacts of flood control, navigation, agriculture and development in the Kissimmee Basin are well documented, and the reader is referred to Loftin et al. (June 1990), Loftin et al. (December 1990), Carroll and Banner (1991), and USACE 1991 for additional detail. Loftin et al. June 1990 captured the essence of the impacts of channelization: "... in addition to direct physical destruction of the river and floodplain habitat which resulted from canal excavation and deposition of soil, channelization has ... impacted the ... ecosystem primarily through altered hydrologic regimes. Ecological consequences ... include diminished floodplain habitat diversity, reduction of wading bird usage of the floodplain, and loss of habitat for forage fish, as well as larger riverine fish species. The nature and rate of energy exchange between the river and floodplain also has been disturbed. Elimination or modification of the river/floodplain interactions has affected the functional integrity of both the river and floodplain. ...Lack of flow has degraded water quality, and led to excessive sedimentation ... diminished habitat quality and diversity, and degraded river biological communities."

RESTORATION

The environmental impacts of channelization were quickly recognized and opposition and calls for restoration of the river began before the Kissimmee River Flood Control Project was complete. Three major studies were conducted to evaluate restoration alternatives. The Corps conducted two studies on the feasibility of restoring the Kissimmee (USACE 1985, and USACE 1991) and the SFWMD (Loftin et al June 1990) prepared a comparison of

restoration strategies. The latter study contained a detailed analysis of hydrologic alternatives. The Corps' 1991 feasibility study and the SFWMD evaluation reached a similar conclusion: reestablishing a fully functional river and floodplain required recovery of the natural hydrologic regime. That could be done most effectively by backfilling most of C-38, connecting the remnant portions of the original river, and delivering water from the Upper Basin in a manner that mimics the natural system.

The restoration plan consists of two geographic components: the Upper and Lower Basins. The restoration plan for the Upper Basin calls for increased water storage and a regulation schedule that provides a more natural downstream hydrology. Lakes Cypress, Hatchineha, Kissimmee, and Tiger will be impacted. Modification of the canals that connect the lakes is under study, but the prevalent view is that major modifications will not be necessary.

The Lower Basin component consists of: backfilling 29 miles of C-38 using dredged material adjacent to the waterway; recarving 9 miles of river channel; removal of two water control structures; degrading floodplain levees; and backfilling borrow canals. The authorized restoration project stops short of full restoration in that S-65, S-65A, S-65D and S-65E will remain as will the Pool A channel, Government Cut and Pool E. A 1000 foot stretch of the canal will be backfilled beginning in 1994, to enable the Corps and SFWMD to better predict environmental and engineering conditions likely to be encountered in future backfilling. Canal backfilling is scheduled to begin in 1998. Construction will require approximately 15 years.

SFWMD RESEARCH PLAN

The SFWMD in cooperation with the FGFWFC, an independent Scientific Advisory Panel, and the Corps has developed "The Kissimmee River Research Plan", hereafter referred to as the KRRP. The KRRP details the first five years of a 15 year $12.5 million monitoring and evaluation plan. The primary focus of the plan is on the evaluation of restoration in the Lower Basin. Upper Basin studies will focus primarily expansion of littoral wetland communities on Lakes Kissimmee, Cypress and Hatchineha. The KRRP is adopted in this report as the fundamental document for the research anticipated for the restoration of the Kissimmee River. It is enclosed as an appendix.

Goal of the KRRP. The overall goal of the KRRP is to measure the pulse of the restoration, monitor construction impacts, measure the success of restoration and allow adaptive management throughout the project's 15-year construction period. The size and lifespan of this project invites mid-course corrections as new information becomes available. The ability to conduct adaptive management will be largely accomplished by the development of an understanding of ecosystem structure and function before and after restoration; demonstration of cause and effect relationship between restoration efforts and ecological responses; quantification of biological responses; and documentation of changes that are of social or scientific significance. In summary, the KRRP will provide information throughout the 15 year construction life of the project which will allow informed fine-tuning of the restoration process.

Approach. The KRRP has adopted a six-phase approach.

- Conceptual Models. Develop conceptual models that describe the ecological factors that govern wading bird, waterfowl, vegetation, fish and invertebrate communities. These models will aid in the understanding of the effects of restoration and interpretation of the ecological evaluation program.

- Reference Conditions. Define reference conditions for impacted systems based on similar location, historical data or theoretical approaches. Reference conditions will apply to the selected plant and animal communities (described above) as well as hydrologic and water quality conditions. They will establish a level of performance against which actual results can be measured.

- Baseline Conditions. Existing conditions will be documented to establish a baseline. The baseline will be measured against the actual restoration results and the reference conditions as an expression of success.

- Construction Impacts. Water quality will be monitored during construction to rapidly recognize and correct problem areas and thereby minimize the impacts of the restoration project.

- Evaluation. The results of restoration will be measured in this phase. The initial opportunity for evaluation would occur in 1995-96, immediately after construction of the 1000 foot test fill.

- Adaptive Management. Adaptive management will be employed to update and fine-tune restoration activities.

Status. The basic restoration research plan, the KRRP, is in final draft form. The KRRP built upon many previous studies and the findings of a Scientific Advisory Panel commissioned to develop a comprehensive ecological monitoring program.

Conceptual models for aquatic invertebrates, fish, wading birds and waterfowl have been drafted. A conceptual model for vegetation is not yet available.

The parameters for the reference conditions have been outlined in the KRRP. Final reports are expected by the end of 1994.

Draft proposals for the development of baseline data and monitoring the response to restoration activities have been received for invertebrates, fisheries, wading birds and waterfowl.

CONSTRUCTION-RELATED MONITORING

Restoration of the Kissimmee River Basin presents several unique engineering, hydraulic and geotechnical features. Monitoring of these features will allow modification and improvements during the protracted period of construction, and will provide answers to questions likely to arise in similar projects. Several aspects of this information will be useful in interpretation of ecological modeling results.

Hydraulic models. Hydraulic resistance over the flood plain following the restoration of wetland vegetation is a critical body of information needed to determine the upstream limit of backfilling and how the Upper Basin should be operated for flood control. The hydraulic monitoring program will measure this critical change in resistance and ultimately the final resistance of the restored flood plain.

Monitoring will be conducted at about thirty water level and velocity vector points in the reach influenced by the first segment of backfilling. Monitoring gages will be installed before reflooding to take advantage of dried flood plain conditions. Stilling wells will be installed such that the first two feet of water table can be measured to allow monitoring of wetting and drying at the edge of the flood plain. Vertical control will be of extremely high order such that required precision in measuring water surface slope is not limited by the precision of the level surveys. A local traverse can be used for control because relative precision between gages within this network is much more important than global precision; however, this gage network should be tied to overall basin water levels at prevailing level precision.

Additional water level monitoring locations will be established in Lakes Kissimmee, Hatchineha, and Cypress in order to better manage operations in that sub-basin. More gage locations will avoid existing problems with wind setup in the lakes which can cause erroneous estimates of average lake stage. Lake regulation schedules are based on stages of hypothetically flat lake surfaces; therefore, average lake stages are preferable for use in daily operations.

Other hydrologic monitoring ongoing in the basin will continue. Rainfall gages presently located at S-65 structures that will be destroyed will be relocated.

Sedimentation monitoring. Because of the uniqueness of this construction project, many of the determination that have been made regarding sedimentation issues have not been site proven in similar settings. The program will begin prior to construction in order to gather baseline data, and will continue until such time as it can be established that the components of the project are stable.

The sediment monitoring program will be designed to include assessment of localized erosion and deposition at backfilled sections, river-canal junctions, and shallowed sections. Final graded and revegetated reaches of any completely backfilled canal reaches also will be monitored. The program also will monitor the stability of banks and bed of the river channels, especially any new river channels excavated to connect remnant river channels. Overall monitoring of the project area will be conducted so that any mass transport to Lake Okeechobee can be detected.

This program will include monitoring of suspended and bed loads at a range of discharge conditions to assure that gradually developing problems with sediment and erosion control, if they occur, do not go undetected and lead to greater or catastrophic problems. In case any do occur, technical analyses and solution approaches will have site specific data.

Stability monitoring. While the constructed features of this project will be subjected to normal inspections, including quality assurance - quality control, and "as-built" comparisons to specifications, long-term monitoring is desirable for some of the features. Features normally submerged and subjected to erosional forces will be monitored to determine stability. Concerns include armoring, unprotected soil in abutment areas, and gross stability of slopes and structural mass. Also, revegetated areas will be monitored for survivability of plants and overall coverage for erosion protection.

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APPENDIX

KISSIMMEE RIVER RESEARCH PLAN

Kissimmee River Research

Prepared By
Staff of the
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South Florida Water Management District

December 1993

December 1, 1993

KISSIMMEE & OKEECHOBEE SYSTEMS RESEARCH DIVISION

MISSION STATEMENT

- Conduct interdisciplinary research to gain a predictive understanding of ecosystem dynamics in the Kissimmee River Basin, Lake Okeechobee basin, Caloosahatchee and St. Lucie River basins and estuaries, and the Upper East Coast and Lower West Coast.

- Design, prioritize and implement research to yield the greatest reduction in management and regulatory decision uncertainty for the least cost.

- Disseminate research products through publication in peer-reviewed scientific and engineering literature.

- Conduct research in disciplines such as limnology, estuarine ecology, civil and agricultural engineering, organismal biology, water chemistry, and river and wetland ecology at a variety of spatial and temporal scales.

- Provide information for decision makers to ensure the protection, enhancement, and restoration of regionally significant ecosystems, and for evaluating tradeoffs among conflicting needs of nature and society.

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SUMMARY

The focus of this five-year research plan will be the initiation of the Kissimmee River restoration evaluation program. The evaluation program will have an ecosystem perspective with an experimental, hypothesis-driven approach. At least six ecological components - hydrology, vegetation, avian, fish, water quality and invertebrates - will be evaluated empirically and through conceptual modelling. The key elements of the five-year research plan are:

1. Develop an action plan for implementation which defines participatory roles of the District and other state and federal agencies

2. Develop conceptual models of the ecological factors, processes and relationships that govern the structure and organization of wading bird, waterfowl, floodplain vegetation, and river fish and invertebrate communities

3. Define reference conditions for evaluation components

4. Establish baseline conditions for evaluation components

5. Monitor water quality impacts of the test fill reach

6. Evaluate the environmental responses to the headwaters revitalization component of the restoration project

Scheduling of the evaluation program is keyed to three planned restoration construction activities: backfilling of a 300 m test reach of canal in October 1993; initiation of the headwaters revitalization component in 1995; and initiation of the first phase of canal backfilling in 1998. A phased approach to restoration evaluation has been adopted to economize District staff requirements.

Other related activities will include active participation in future restoration planning and publication of restoration-related research in peer-reviewed scientific and engineering literature.

The research plan consists of a chronology of Kissimmee River research (Figure 1) showing milestones overlaid on a background of funding levels. The figure is followed by flow diagrams showing how each research question has been or will be

addressed, time frames (Figures 2 and 3) and relevant references (Table 1) including both in-house and contractual research reports. Projects are designated as completed, ongoing or planned. Flow diagrams are followed by a Gantt chart (Figure 4) of the plan with task descriptions and time lines.

KISSIMMEE RIVER RESEARCH PLAN

Introduction

Environmental resources of the Kissimmee River basin have been studied for over 40 years. The primary impetus for these efforts has been the Central and Southern Florida Flood Control Project which resulted in channelization of the river. Studies documenting the ecological impacts of channelization and evaluations of the utility of various restoration measures began in the early 1970s. These studies initially had two somewhat independent areas of emphasis. One line of investigation dealt with water quality issues and the value of Kissimmee River restoration as a means to prevent or reverse accelerated eutrophication of Lake Okeechobee. Other studies focused on the impacts to and restoration of biological resources in the Kissimmee valley.

At least part of the early impetus for restoration was derived from concern that channelization of the river had bypassed nutrient absorption processes on the floodplain and thereby created a conduit for rapid downstream transport of nutrient loads into Lake Okeechobee. Although early restoration-related studies identified agricultural runoff, particularly from improved pasture and dairy operations, and associated secondary drainage systems, as the primary causes of elevated nutrient loads in the channelized system, the nutrient removal capabilities of Kissimmee floodplain marshes also were verified. However, these studies indicated that reestablishment of the nutrient filtration function will be effective only if hydrologic characteristics of the former floodplain wetlands are restored and elevated nutrient inputs generated by intensive agricultural land uses are reduced at their source. Subsequently, low summer and fall dissolved oxygen regimes were identified as the primary water quality related problem, and a principal cause of deterioration of biological communities in the channelized system.

Channelization replaced the meandering river with a 90 km long, 9 m deep and 64-105 m wide canal (C-38), which, along with its water control structures, transformed the contiguous river/floodplain ecosystem into a series of five impoundments. The excavation of C-38 and deposition of spoil obliterated 56 km of river channel and 2800 ha of floodplain, and water levels were stabilized at stages that completely drained the floodplain in the upper two-thirds of each pool. In the absence of flow, thick deposits of organic matter accumulated on the bottom of the remaining river channel, and reduced depth and substrate diversity within these stagnant, remnant river courses.

These physical impacts led to significant changes in the biological, chemical and

functional characteristics of the river ecosystem. In addition to the wetlands that were destroyed by the canal and spoil, at least 12,000 ha of the floodplain wetland mosaic were replaced by broad expanses of relatively homogenous unimproved and improved pasture communities. Elimination of floodplain wetlands and stabilization of water levels within the remaining impounded wetlands led to a 74% decrease in the number of active Bald eagle (*Haliaeetus leucocephalus leucocephalus*) territories and 92% reduction in wintering waterfowl. The diverse community of wading birds that formerly utilized the floodplain has been replaced by dominant populations of the naturalized cattle egret (*Bubulcus ibis*), a species that occurs primarily in association with cattle on pasture and other ruderal, upland habitats. Drainage of wetlands also virtually destroyed the floodplain food web, including a constant source of over five billion forage fish and six billion freshwater shrimp.

Other biological impacts occurred as a result of habitat alteration and degradation associated with the transformation of the river into a series of impoundments. Benthic invertebrate communities in the canal and remaining river runs display low densities and diversity and are dominated by larval phantom midges (*Chaoborus punctipennis*), a species which is characteristic of a lentic rather than riverine environment. Fish species richness in remnant river habitats has declined from 39 to 17 species; two species have been extirpated and game fish populations appear to be undergoing a continuous, long-term decline.

This broad array of environmental impacts provided a solid foundation for the restoration initiative, but presented a challenge for formulation of a restoration plan. Through most of the years of study that preceded development of the adopted river restoration plan, proposed restoration measures used select resource values (e.g., wetlands, game fish, waterfowl, wading birds, and water quality) as independent objectives. Evaluations of alternative restoration measures also were conducted as if targeted river and floodplain resources and functions were independent values.

The adoption of a holistic ecosystem restoration goal - **reestablishment of ecological integrity** - was a pivotal event in the restoration planning process, and emanated from a 1988 symposium on the restoration initiative. By definition, this goal requires "reestablishment of an ecosystem that is capable of supporting and maintaining a balanced, integrated adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of the region". The ecological integrity goal shifted the focus of restoration planning from independent objectives involving discrete taxonomic components or ecological functions to the organizational determinants and self-sustaining properties of river/floodplain ecosystems.

Establishment of the goal led to the development of a comprehensive set of restoration guidelines and criteria. These guidelines and criteria were founded upon

the physical form and hydrologic determinants of ecosystem integrity that were altered by channelization and other aspects of the flood control project and provided a rigorous and objective basis for analyses of alternative restoration plans.

Integration of available data on pre-channelization resources, impacts of channelization, and restoration-related studies led to the development and adoption of the current plan to restore the ecological integrity of the Kissimmee River ecosystem. This plan consists of two integrated components. The lower basin component will restore the physical form of the river and floodplain by:

- backfilling 35 km of canal using the adjacent dredged spoil material from the original canal excavation
- recarving 14 km of river channel to reconnect remnant river channels in areas where the excavation of C-38 or placement of excavated material obliterated former river channel
- removal of two of the water control structures and their tieback levees and
- degradation of other floodplain levees or berms and backfilling of the borrow canals for these levees and secondary drainage canals within the floodplain.

The Headwaters Revitalization component will reestablish inflow characteristics that are necessary to reestablish the hydrologic determinants of ecosystem integrity. The 1992 Water Resources Development Act authorized restoration construction and a federal-state, cost-sharing partnership for its implementation. Initiation of the headwaters component is expected to begin in 1995 while the first phase of canal backfilling is scheduled to start in 1998. Construction will take approximately 15 years to complete.

The Kissimmee River five-year research plan was developed to facilitate implementation of the restoration plan and has three major objectives:

(1) Provide continual scientific input and support for the detailed design phases of both the headwaters revitalization and lower basin components of the restoration project;

(2) Develop, coordinate, implement and integrate an ecological evaluation and research program for the restoration project, with adaptive management-related objectives;

(3) Disseminate restoration-related research results through peer-reviewed scientific publications.

The ecological evaluation program will be the cornerstone of research activities provided by this five-year plan. The following implementation plan describes the proposed restoration evaluation program, including details of initial study phases. Further study design details will be developed in the upcoming year. Annual updates and modifications of the five-year research plan will provide details of the restoration evaluation program through the 15-year construction period.

SECTION I

IMPLEMENTATION PLAN FOR THE KISSIMMEE RIVER RESTORATION EVALUATION PROGRAM

1.1 Evaluation Program Goals

The ecological evaluation program will measure the pulse of the restoration project and will have four conceptual goals:

- Provide a thorough understanding of ecosystem structure and functions before and after restoration
- Show direct cause-effect relationships between restoration efforts and ecological responses
- Include quantifiable biological responses and hypothesis-driven experimental approaches
- Document changes that are of social and scientific importance

1.2 Background

The 1992 Water Resources Development Act authorizes construction of both the upper and lower Kissimmee basin components of the Kissimmee River ecosystem restoration plan. The South Florida Water Management District has agreed to enter into a 50/50 cost-sharing agreement with the U.S. Army Corps of Engineers to complete the restoration project, which includes environmental monitoring of the upper basin component and a comprehensive ecological evaluation program for the lower basin.

In August 1991, a District-commissioned Scientific Advisory Panel, with technical input from the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Florida Department of Environmental Regulation, Florida Game and Fresh Water Fish Commission, Florida Department of Natural Resources, St. John's River Water Management District and the South Florida Water Management District, provided recommendations for the design of the lower basin restoration evaluation program. These recommendations included prioritized evaluation components and a five-phase

framework for implementation.

1.3 Purpose

The purpose of this research program is to document and evaluate ecological responses to the ecosystem restoration plan and provide for continuous, scientifically-informed fine-tuning of restoration efforts.

SECTION II

PROJECT DESCRIPTION

The restoration evaluation program, like the restoration approach, must have an ecosystem perspective. Because the headwaters component of the project is being conducted to achieve the goal of restoring the ecological integrity of the lower basin ecosystem, the primary focus of the evaluation program will be on the river/floodplain ecosystem in the lower basin.

Based upon recommendations of the Scientific Advisory Panel and subsequent input from state and Federal agencies, the District is recommending a comprehensive restoration evaluation program that includes a variety of taxonomic components as well as habitat-based and process-oriented approaches. Proposed taxonomic components include littoral and floodplain vegetation, wading birds, waterfowl, fish, aquatic invertebrates and resident endangered species. All of these components except the endangered species should be evaluated at the community level. Principal habitat components will include hydrologic characteristics, water quality and the diversity and stability of physical parameters along the river channel. The scope of functional studies will be limited by manpower and resource constraints, but at a minimum needs to include analyses of processes that regulate dissolved oxygen regimes.

The upper basin monitoring program will focus on the expansion of littoral wetland communities on Lakes Kissimmee, Cypress and Hatchineha.

2.1 Lower Basin Ecological Evaluation Program Components

2.1.1 Hydrology.

Hydrologic studies will determine if restoration measures are successful in reestablishing the key hydrologic determinants of ecological integrity of the river/floodplain ecosystem. Results will provide for continual, scientifically informed fine-tuning or "adaptive management" of the restored ecosystem. Associated monitoring of the hydraulic resistance over the restored floodplain is needed to determine the upstream limit of backfilling and flood control operation criteria for the Upper Basin.

2.1.2 Habitat Structure, Sedimentation and Stability

Evaluations of river channel habitat parameters such as channel morphology and substrate characteristics will provide correlates for biological responses. The restored river channel, particularly excavated channels, will be closely analyzed for localized erosion, deposition and stability.

2.1.3 Vegetation Communities

Littoral and floodplain vegetation is the basis for the productivity and health of the Kissimmee River ecosystem. Vegetation is the principal structural habitat determinant, as well as the base of food web in the river/floodplain ecosystem.

2.1.4 Birds

Extensive studies of wading birds and waterfowl is needed because of their visibility (societal importance), and because they reflect different feeding guilds and are good indicators of the productivity and general health of the system. These studies will include special focus on evaluations of endangered species (i.e., bald eagle, wood stork and snail kite) responses.

2.1.5 Fish

Fish will be evaluated because they are valued by society for sport and food, and their abundance and health affect and reflect conditions in the ecosystem. The contribution of fish community sampling to understanding the river/floodplain is high because of the large number of fish species that occur within the system.

2.1.6 Water Quality

The highest priorities of water quality evaluations will involve assessments of construction-related impacts and dissolved oxygen dynamics. Construction impact assessments will ensure that temporary or incidental water quality impacts (e.g., suspended solids and turbidity) are minimized. Dissolved oxygen studies are required because of the limiting role this parameter exerts on biological communities in the channelized system. Other water quality parameters that will be monitored include nutrients and organic carbon. Nutrients are important because of their significance downstream (in Lake Okeechobee) and because of their ecological role in the river/floodplain ecosystem. Because the energy base of the restored ecosystem will change during restoration, evaluations of changes in the quality and quantity of organic matter (carbon) transported through the ecosystem is central to understanding the limits and opportunities in system management.

2.1.7 Invertebrates

Invertebrates are the second link (primary consumers) in the food web, provide a food source for secondary consumers, and are indicators of habitat conditions. Invertebrates are good indicator taxa because they are usually sedentary and integrate changes over large spatial and long temporal scales. Invertebrate communities will be studied within the river channel and on the floodplain.

SECTION III

DESCRIPTION OF TASKS

Implementation of the evaluation program will involve a six-phase approach:

3.1 Development of Conceptual Models

A suite of conceptual models will be developed for each evaluation component. These models will describe the ecological factors, processes and variables that govern the structure and organization of wading bird, waterfowl, vegetation, fish and invertebrate communities, and will focus on those factors and variables that that will likely be the key parameters in eliciting responses by these communities. The conceptual models will facilitate understanding of the effects of restoration on ecosystem and landscape pattern and process, and insure adequate design of the restoration research plans and interpretation of results of the ecological evaluation program.

3.2 Definition of Reference Conditions

This phase will establish expectations for each evaluation component. Reference conditions may be based upon a reference site or location, historical data or theoretical approaches. Because the restoration project will be constructed in phases, reference conditions must have a spatial and temporal aspect that will allow for continuous evaluation and tracking of restoration success during and after the construction period. A temporal aspect also is needed to differentiate between short and long-term restoration responses, and to account for the variability in population and community structure that likely occurred in the historic system and consequently is expected in the restored ecosystem.

The scope of each set of reference conditions will be consistent with the conceptual models that have been developed for the evaluation components. The rationale, methods and schedule for defining reference conditions for each of the ecological components of the restoration evaluation program follow.

3.2.1 Wading Birds

Information on composition and relative abundances of wading bird species that utilized the historic river and floodplain are provided by Perrin et al. (1982) and in unpublished Audubon reports dating back to the 1930s. The Audubon reports provide some quantitative data but are based upon inconsistent or undefined censusing methods. Realistic expectations for restoration of wading bird communities must reflect the impacts that have affected populations of these species throughout the

south/central Florida landscape. Reference conditions for wading birds will include expectations for population densities of select species and/or guilds, establishment of rookeries and other breeding sites, and other habitat-based projections. These expectations will be based upon the Audubon reports and published literature on habitat utilization by the various species that occur in the basin.

3.2.2 Waterfowl

Quantitative historical data on wintering waterfowl populations on the Kissimmee River floodplain were collected between 1949-57 by the U.S Fish and Wildlife Service and Florida Game and Fresh Water Fish Commission. Although about 50% of the primary habitat (wet prairie) utilized by wintering waterfowl in the historic system will be restored, expectations for waterfowl, like wading birds, must reflect the impacts that extraneous factors have had on both regional and migratory waterfowl populations. Target reference conditions will focus primarily on projections of increased usage of the floodplain, specifically the reestablished wet prairie habitat, by resident mottled ducks and migratory dabbling ducks.

3.2.3 Fish

One set of historical data on fish communities in various river and floodplain habitats was collected between 1955-57 by the Florida Game and Fresh Water Fish Commission. Although a variety of methods were employed, gear selectivity and lack of information on spatial and temporal variability precludes a comprehensive quantitative characterization of historic fish community structure. Reference conditions for fish communities need to include a variety of metrics, such as species composition, diversity, abundance, indicator taxa, recruitment dynamics, and river channel and floodplain habitat utilization, including any differentiation among life history stages (e.g., feeding, reproduction, refuge, etc.). Defining these reference condition metrics for Kissimmee River fish communities likely will require establishment of reference sites as well as use of theoretical (e.g., literature-based) expectations to supplement historical data. The search for potential reference sites initially will focus on the stream systems within or near the Kissimmee River basin, but if necessary, will be expanded to include other river systems within the Southern Coastal Plain Ecoregion of Florida. If adequate reference sites are not identified in these areas, other Lower Coastal Plain rivers of Florida, Alabama, Georgia, North Carolina and South Carolina will be investigated. If a reference site is established, subsequent sampling may be conducted to incorporate long-term variability patterns in reference conditions.

3.2.4 Invertebrates

No historical data on invertebrate communities of the Kissimmee River have been published. Like expectations for fish communties, reference conditions for invertebrates should include a range of metrics, such as species composition,

diversity, abundance, river and floodplain habitat utilization, indicator species and trophic structure. These reference metrics will be established through a joint effort by scientific staff of the South Florida Water Management District and Florida Game and Fresh Water Fish Commission. They will be based upon published literature on invertebrate communities of other similar, but unimpacted river systems, establishment of a reference site and any information that may be derived through a search of university and state invertebrate collections. The search for potential reference sites initially will focus on the stream systems within or near the Kissimmee River basin, but if necessary, will be expanded to include other river systems within the Southern Coastal Plain Ecoregion of Florida. If adequate reference sites are not identified in these areas, other Lower Coastal Plain rivers of Florida, Alabama, Georgia, North Carolina and South Carolina will be investigated. If a reference site is established, subsequent sampling may be conducted to incorporate long-term variability patterns in reference conditions.

3.2.5 Floodplain Vegetation Communities

Maps of prechannelization floodplain vegetation community distributions have been constructed from analyses of historic (1952-54) aerial photographs (Pierce et al., 1982). Based upon the assumption that the historic spatial distribution of plant communities will be reestablished following restoration of historic hydrologic characteristics (an assumption that appears to have been verified by demonstration project studies), these maps provide an excellent basis for floodplain vegetation reference conditions. However, some adjustments and refinements are needed. For example, floodplain habitats that were formerly dominated by woody species and were cleared after the floodplain was drained cannot be expected to return to the historic state following reflooding, at least during a proximate time scale. Perhaps, more significantly, the existing interpretations of historic photography provide only broad distribution patterns of major plant community types. Further analyses of the historic photography will be conducted to more precisely define and characterize the distributional mosaic of habitat patches along and across the floodplain.

3.2.6 Littoral Vegetation Communities

No historical information of littoral vegetation communities is available. Historical aerial photographs will be used to at least quantify the aerial extent, and possibly differentiate the types of littoral vegetation communties that occurred along the prechannelization river channel.

3.2.7 Hydrology

The historical data base includes 16-30 years of discharge data at three locations along the river and 25-37 years of stage data at four river locations. These data provided the basis for the five criteria that have been established as the prechannelization hydrologic determinants of ecological integrity and were used to

select the restoration plan. The hydrologic reference conditions for the restoration project will be based upon these criteria.

3.2.8 Water Quality

No prechannelization water chemistry data is available. The principal parameters requiring reference conditions are dissolved oxygen, nitrogen and phosphorus concentrations, and possibly organic carbon fractions. Expectations for dissolved oxygen regimes will be determined using a dissolved oxygen model of the system that is currently being developed. This model also will be capable of providing realistic expectations for nutrient concentrations in the restored river system. Less precise expectations will be developed for organic carbon dynamics, including coarse, fine and dissolved organic matter, and will be based upon published data from other similar river systems.

3.3 Establishment of Baseline Conditions

In this phase, existing conditions will be documented for comparison with the expected (reference) conditions, and ultimately with actual conditions achieved by restoration. The scope and design of baseline studies will be based upon the conceptual models and reference condition metrics that are established for each evaluation component. Baseline studies will be centered in Pool C (the area that will be affected by the first phase of restoration) and will include control sites in other pools. At least two years of pre-construction baseline data will be collected for all components.

Baseline studies for evaluating environmental benefits in the headwater lakes (i.e., to the Headwater's Revitalization Component) will focus primarily on the expansion of littoral wetland communities.

3.4 Construction Impact Monitoring

These assessments will ensure that temporary or incidental environmental impacts are documented and minimized over the planned 15-year construction period. An early indication of potential construction impacts will be provided through environmental studies associated with the planned "test fill" project. This test project is scheduled for October 1993 and will backfill 300 m of canal and degrade 5.2 ha of adjacent spoil to pre-canal floodplain elevations. The test-fill project is intended primarily to evaluate fill consolidation and construction methodology, but provides the opportunity for environmental assessments that will be used to fine-tune the restoration plan.

3.4.1 Test-Fill Evaluation Plan - Potential Impacts on Water Quality

The principal water quality concerns relating to the test-fill are turbidity, suspended solids transport, dissolved oxygen regimes, and to a lesser extent, nutrient export from resuspended sediments. Core borings indicate that the spoil mound that will serve as the source of backfill material consists primarily of coarse sand and shell with a small clay component. Due to the canal's hydraulics (i.e., capacity to carry high discharges at low velocities) the potential for sediment transport in the canal is extremely low. Consequently, most suspended backfill material is expected to quickly settle, although suspension of the clay component could result in high localized turbidity levels in the vicinity of the backfilled reach.

Low dissolved oxygen concentrations are the principal water quality problem within the channelized system. During the summer and fall months the canal is stratified and dissolved oxygen concentrations range from about 2.0 mg L^{-1} at the surface to < 1.0 mg L^{-1} at depths below 1 m. By reducing light penetration, construction-generated turbidity could depress dissolved oxygen concentrations within the surface strata even further. There also may be potential for construction to cause the canal to overturn and mix deoxygenated water from the subsurface stratum with the oxygenated surface layer.

Another potential water quality issue involves effects of flow over the test fill plug and degraded spoil area, and the diversion of flow from the canal to adjacent remnant river channels. The test-fill location occurs downstream of a weir that has already diverted a portion of canal discharge (up to 60% during high flows) through the main remnant river channel. This diverted flow has flushed accumulated organic deposits out of the main adjacent remnant river channel without any detectable increases in nutrient loads downstream. However, because the test-fill plug will divert all canal flow through this remnant river channel and another short section of remnant river immediately upstream of the plug, there is some possibility that more organic matter deposits and associated nutrient loads will be flushed downstream. It also is possible that flow over the test-fill plug and degraded spoil area will release nutrients from any newly exposed organic soils.

The ecological evaluation studies for the test-fill project are designed to address four water quality hypotheses:

Hypothesis #1 - There will be no statistically significant downstream transport of suspended solids.

Hypothesis #2 - Construction-generated turbidity will dissipate within a short time period and will be highly localized in the vicinity of the test-fill plug.

Hypothesis #3 - There will be no statistically significant increase in nutrient concentrations or loads downstream of the test-fill construction site.

Hypothesis #4 - Any construction-related impacts on dissolved oxygen regimes (profiles) will be highly localized in the vicinity of the test-fill plug.

These hypotheses will be evaluated by sampling at five sites (Figure 5):

Site 1 - Mid-canal location immediately upstream of the confluence of the remnant river channel adjacent to the lowermost Demonstration Project weir. This site will provide data on ambient water quality for the canal upstream of the plug, and the source of inflow to the main remnant river channel adjacent to the plug.

Site 2 - Mid-remnant river channel location slightly north of the location of the test fill plug. This site will provide information on changes in water quality associated with flow through the remnant river channel.

Site 3 - Mid-canal location approximately 100 m downstream of the test fill plug. This site will provide information on localized effects of the test fill on water quality in the canal.

Site 4 - Mid-remnant river location at the confluence with the canal downstream of the test fill plug. This site will provide information on localized effects of the test fill and any associated lateral diversion of flow on water quality in the main remnant river channel adjacent to the test fill plug.

Site 5 - Mid-canal location immediately upstream of S-65B. This site will provide information on the downstream extent of any influence of the test fill on water quality. Water quality data are available from this site since 1972.

The historical data base (1972 - present) of monthly water quality samples from the canal immediately upstream of S-65B will be analyzed to establish baseline (pre-construction) conditions and variability, and to optimize sampling frequencies for turbidity, suspended solids and nutrient parameters. Baseline conditions for dissolved oxygen regimes are provided by one year (1989) of bi-weekly dissolved oxygen profiles at 1 m depth intervals from several canal and remnant river locations in the vicinity of the test-fill site. In addition to these data, at least three months of pre-construction data on these water quality parameters will be collected at the five test-fill sampling sites. These data will indicate the extent of any longitudinal variation.

The hypothesized "localized" and "temporary" effects of the test-fill construction on water quality parameters will be tested by statistical comparisons of

data collected on each parameter at the three canal stations during three 3-month sampling intervals (pre-construction, during construction, and post-construction). Statistically significant differences between the upper and lower stations (sites 1 and 5) during either the construction or post-construction sampling interval will indicate that the effects of construction were not localized. Should this occur, the source of the downstream impacts will be identified more precisely through analyses of data collected at sites 2, 3 and 4. Statistically significantly differences between the upper and lower stations during the post-construction sampling interval will indicate that the effects of construction were not temporary. Subsequent sampling will indicate how long any downstream effects occur.

Suspended solids and nutrient fractions (orthophosphate, total dissolved phosphorus, total phosphorus, nitrate, nitrite, ammonia, total Kjeldahl nitrogen, and total dissolved Kjeldahl nitrogen) will be sampled at sites 1-5 using a Niskin-type sampling bottle at a depth of one meter. Grab samples will be collected at weekly intervals at each site beginning in September 1993 and will continue for at least one year after construction is completed. More frequent (daily) samples will be collected periodically during construction and during high discharge periods. Periodic suspended solids samples also will be collected at depths of 4 m and 7 m at site 3 and site 5 during the construction period. An additional sampling site on the test-fill plug may be added to this sampling regimen after construction is complete.

Weekly Hydrolab measurements of dissolved oxygen concentrations will be taken along the surface to bottom depth profile at sites 1-5 beginning in September 1993 and continuing for at least one year after construction is completed. Dissolved oxygen and temperature also will be sampled with continuous recorders set at depths of one meter at sites 1, 3 and 5 beginning at least one month prior to construction and continuing for one year after construction is completed.

Turbidity samples will be taken at middepth 150 m downstream of the fill site in the densest portion of any visible plume and at a background site 250 m upstream of the plug. Samples will be taken at these locations twice daily, at least four hours apart. Turbidity also will be sampled at site 5 at biweekly intervals from August 1993 through the end of the construction period.

Quality control/quality assurance measures will be taken for all water quality sampling. Replicate autosamplers will be installed at least at one of the sampling locations. Samples for suspended solids and nutrients will be preserved at 4° C and analyed within 7 d and 28 d respectively of collection.

3.5 Post-construction Evaluation

This phase will be the most complex aspect and phase with the longest duration. Restoration of some biological components could be a relatively slow process, but documentation of short-term trends will provide critical information for the fifth phase of the evaluation program, adaptive management.

Initial post-construction studies will conducted in association with the October 1993 test-fill project. While the Kissimmee River restoration plan has a more remunerative ecosystem restoration goal, the test-fill project will reestablish approximately 7 ha of emergent wetland habitat on the backfilled canal and degraded spoil area. Previous studies have demonstrated the feasibility of reestablishing wetland plant communities on reflooded sections of drained floodplain and in areas where low berms have been degraded. However, the composition, rate and succession of wetland plant community reestablishment may be different on the degraded spoil area and on the relatively sterile spoil material that will be used to backfill the canal.

3.5.1 Test-Fill Evaluation Plan - Nature and Rate of Reestablishment of Wetland Plant Communities on the Backfilled Canal and Degraded Spoil Area.

Post-test-fill evaluation studies are designed to address the following hypothesis:

Hypothesis - The wetland plant community reestablished on the test fill plug and degraded spoil area will have a species composition comparable to that which existed on this section of floodplain prior to channelization.

This hypothesis will be evaluated by random quadrat sampling on the test fill site and the adjacent 5.2 ha area where the spoil bank will be degraded (Figure 5). Plant species composition will be documented within 30 randomly placed 1 m^2 quadrats within both the test-fill and degraded spoil areas. Plant species composition will be documented within both areas after construction is completed and at four month intervals for two subsequent years, and annually for two more years. Ten 0.5 m^2 standing crop biomass samples will be taken at random points within the test-fill plug areas and degraded spoil area in September-November 1994 (at the end of the peak growing season) and during these months for three subsequent years. Plant community data will be compared to previously collected plant community composition and standing crop biomass data from existing floodplain wetlands in the lower end of Pool B.

3.6 Adaptive Management

This phase will utilize information in all previous phases to provide for continual, scientifically informed fine-tuning of the restoration project and associated land and water management components.

SECTION IV

IMPLEMENTATION SCHEDULE

The schedule for the restoration evaluation program is dictated by planned construction milestones. Reference and baseline conditions for all evaluation components need to be established prior to initiation of the first phase of canal backfilling, which is scheduled to begin in 1998. Similarly, reference and baseline conditions for the headwaters project need to be established prior to the planned initiation of this component in 1995.

To economize staff and budgetary commitments, the definition of reference conditions and establishment of baseline conditions for the first reach of backfilling will be phased over the four-year period. Reference conditions for all components will be defined by November 1994. Although some subsequent refinements may occur, the scope of each set of reference conditions must be largely established prior to design and implementation of the field studies component of the baseline evaluation phase. The design of baseline studies for fish and invertebrate communities, including any pilot studies that are needed to establish sampling methodology or protocol, will be completed by January 1994. These study designs will be reviewed by a Scientific Advisory Panel (see RESOURCES) in February 1994, after which baseline studies of these components will be initiated. Study designs for compiling baseline data for other evaluation components will be completed in 1994, with initiation of these studies occurring in 1995.

The test-fill evaluation plan for documenting and assessing impacts of construction on water quality and documenting the nature and rate of reestablishment of wetland plant communities on the backfilled canal and degraded spoil area will be reviewed by the Scientific Advisory Panel in August 1993 and implemented in September 1993.

Scheduled construction milestones and associated evaluation requirements form the basis for the pre-construction implementation timeline shown in the Gantt Charts (Figure 4).

SECTION VI

RESOURCES

The authorized project costs are based upon the 1991 U.S. Army Corps of Engineers feasibility report on the restoration project, which allocate $180,000 for upper basin monitoring and $15,642,000 for the lower basin hydrologic/ecological evaluation program. The following breakdown shows preliminary cost allocations for lower basin evaluation components for the pre-construction reference and baseline condition phases and 15 years of subsequent evaluation studies:

Avian Studies	$1.8 M
Fish Studies	$3.0 M
Habitat Structure and Stability	$1.7 M
Hydrologic Studies	$2.5 M
Invertebrate Studies	$2.5 M
Vegetation Studies	$2.3 M
Water Quality Studies	$1.7 M
Mobile Research Lab	$142 K

The first five years of the restoration evaluation program will implemented primarily by the South Florida Water Management District and Florida Game and Fresh Water Fish Commission. Other participants could include the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Florida Department of Environmental Protection, experts from academia, and services of private consulting firms. Further definition of the participatory roles of the various state and federal agencies will be early step in the implementation plan. An independent Scientific Advisory Committee will be commissioned to guide and review research and evaluation activities and thereby insure the success of the restoration evaluation program.

As local sponsor of the restoration project, the District will assume the leadership role in the coordination and integration of the research efforts. The District also will have an active research team. Staffing of the District research team presently includes one Senior Environmental Scientist (Team Leader), one Staff Environmental Scientist, and one Scientific Technician. A temporary (one-year appointment) Senior Environmental Scientist has been budgeted for FY 93-94. Depending upon the participatory roles of other agencies in the evaluation effort, other temporary or permnanent staff may be needed during FY 94 – 95 through FY 96 – 97.

Table 1. Kissimmee River Restoration Research Projects

Ref. No.	Title	Start	End	Organization	Product
1	Water quality characteristics of Kissimmee River	1971	1973	USGS	Lamonds, 1975
2	Water quality characteristics and benthic invertebrates of Kissimmee Chain of Lakes	1973	1975	SFWMD	Milleson, 1975 (Tech Pub 75-2 DRE-55)
3	Hydrology and water quality of Lower Kissimmee Basin		1976	University of Florida, Huber et al.	Final report, 1976
4	Special project to prevent eutrophication of Lake Okeechobee	1973	1976	Florida Dept. of Administration (multi-agency)	Report, 1976
5	Nutrient loads and assimilation in Chandler Slough	1974	1976	SFWMD	Federico et al., 1978 (Tech Pub 78-2, DRE-84)
6	Water quality characteristics of Upper Kissimmee Basin	1981	1982	SFWMD	Jones et al., 1983 (Tech Memo DRE-167)
7	Water Quality characteristics of Lower Kissimmee Basin	1973	1978	SFWMD	Federico, 1982 (Tech Pub 82-3, DRE-154)
8	Nutrient assimilation potential of restored Kissimmee River marshes	1974	1975	Fla. Div. of State Planning Fla Coastal Engrs	Final Report, 1975
9	Evaluation of restoration measures	1976	1983	Kissimmee River Coordinating Council	McCaffrey, et al 1977
10	Nutrient assimilation in Boney Marsh	1975	1991	SFWMD	Davis, 1981 (Tech Pub 81-1,DRE 127)
11	First feasibility study on Kissimmee River restoration	1975	1985	U. S. Army Corps of Engineers	Report, 1985
12	Effects of alternative Kissimmee River restoration measures on water quality	1982	1985	Water and Air Research, Inc.	Final report 1985
13	Water quality of river tributaries and evaluation of measures to reduce nutrient loads	1978	1982	SFWMD	Goldstein, 1985, 1990 (Tech Pub 86-2, DRE-222, KRR Symp. Proc 1990)
14	Second feasibility study on Kissimmee River restoration	1991	1991	U. S. Army Corps of Engineers	Report, 1991
15	Kissimmee River/Lake Okeechobee monitoring	1971	1971	Fla. Game and Fresh Water Fish Commission	Ager, 1971
16	Ecological characteristics of channelized Kissimmee River system and evaluation of restoration measures	1972	1982	Fla. Game and Fresh Water Fish Commission	Perrin et al., 1982
17	Dissolved oxygen studies on Kissimmee River tributaries	1983	1984	Fla. Institute of Technology	Final report, 1984
18	Water quality and macroinvertebrate monitoring during Kissimmee demonstration project	1984	1989	Fla. Dept. of Environmental Regulation	Rutter et al., 1986, 1989
19	Pool B dissolved oxygen	1989	1989	SFWMD	Toth, unpub. data
20	Analysis of 1988 Kissimmee River fish kill	1988	1988	SFWMD, Fla. Game and Fresh Water Fish Commission	Toth, et al., (KRR Symp. Proc, 1990)
21	Pool B demonstration project monitoring	1984	on-going	Fla. Game and Fresh Water Fish Commission	Wullschleger et al., 1990; Fla. Game and Fresh Water Fish Commission, 1992
22	C-3205 - Dissolved oxygen modeling study $125,000	1992	1994	Howard Searcy, Consulting Engineers	Due Feb, 1994
23	Restoration plan evaluations and preliminary design	1986	1990	SFWMD	Loftin et al., 1990
24	Evaluation of fish and wildlife resources of historic Kissimmee River	1948	1957	Fla. Game and Fresh Water Fish Commission	Report, 1957

Table 1. Kissimmee River Restoration Research Projects- continued

Ref. No.	Title	Start	End	Organization	Product
25	Water quality modeling of C-38	1974	1975	Water Resources Engineers	Final report, 1975
26	Evaluation of fish and wildlife resources of the historic Kissimmee River	1955	1958	U.S. Fish and Wildlife Service	Report, 1959
27	Impacts of channelization and evaluation of potential ecological benefits of water level manipulations	1972	1974	SFWMD	Dineen, et al, 1974 (in depth report, Vol 2, No. 2)
28	Effects of water level manipulations and other management measures on floodplain vegetation	1972	1973	SFWMD	Goodrick and Milleson, 1974 (Tech Pub 74-02, DRE-40)
29	Pre- and Post-channelization floodplain vegetation maps and cattle carrying capacity	1974	1976	Florida Div. of State Planning	Pruitt and Gatewood, 1976
30	Impacts of channelization on ecological resources	1979	1979	U. S. Fish and Wildlife Service Report	Report, 1979
31	Post-channelization floodplain vegetation communities	1978	1980	SFWMD	Milleson et al., 1980 (Tech Pub 80-07, DRE 113)
32	Impacts of channelization on Bald eagle nesting	1959	1979	Fla. Game and Fresh Water Fish Commission	Shapiro et al., 1982
33	Post-channelization Paradise Run fisheries	1987	1987	Fla. Game and Fresh Water Fish Commission	Davis, et al., 1990 (KRR Symp Proc, 1990)
34	Ecological impacts of channelization	1988	1988	SFWMD	Toth, 1990 (KRR Symp Proc, 1990)
35	Historical Kissimmee River fisheries	1955	1957	Fla. Game and Fresh Water Fish Commission & U. S. Fish and Wildlife Service	Miller, 1990 (KRR Symp Proc, 1990)
36	Impacts of channelization on fish and wildlife resources	1979	1979	Fla. Game and Fresh Water Fish Commission	Montalbano et al., 1979 (U.S.D.A. General Tech Report RM-65
37	Environmental benefits of water level manipulations in C-38 impoundments	1971	1973	SFWMD	Milleson, 1976 (Tech Pub 76-03, DRE-70)
38	Kissimmee River restoration recommendations	1988	1988	Fla. Game and Fresh Water Fish Commission	Egbert, 1990 (KRR Symp Proc, 1990)
39	Evaluation of measures to restore Kissimmee River waterfowl habitat	1988	1988	Fla. Game and Fresh Water Fish Commission	Johnson and Turnbull, 1990 (KRR Symp Proc, 1990)
40	Kissimmee River restoration recommendations	1988	1988	Karr	1990 (KRR Symp Proc, 1990)
41	Effects of reestablished flow and water level manipulations on littoral and floodplain vegetation	1984	1988	Fla. Game and Fresh Water Fish Commission	Miller et al., 1990 (KRR Symp Proc, 1990)
42	Effects of Pool B Demonstration Project on wading birds and waterfowl	1987	1988	Fla. Game and Fresh Water Fish Commission	Toland, 1990 (Krr Symp Proc, 1990
43	Required components of a Kissimmee River restoration plan	1988	1988	SFWMD	Toth, 1990 (KRR Symp Proc 1990)
44	Importance of flow to Kissimmee River fish communities	1088	1988	Fla. Game and Fresh Water Fish Commission	Wullshleger et al., 1990 (KRR Symp Proc, 1990)
45	Environmental responses to Kissimmee River demonstration project	1984	1988	SFWMD	Toth, 1991 (Tech Pub 91-02)
46	C91-2562-68 - $16,095 - Recommendations for ecological evaluation program for Kissimmee River restoration	1988	1988	Karr et al	Final Report, 1988

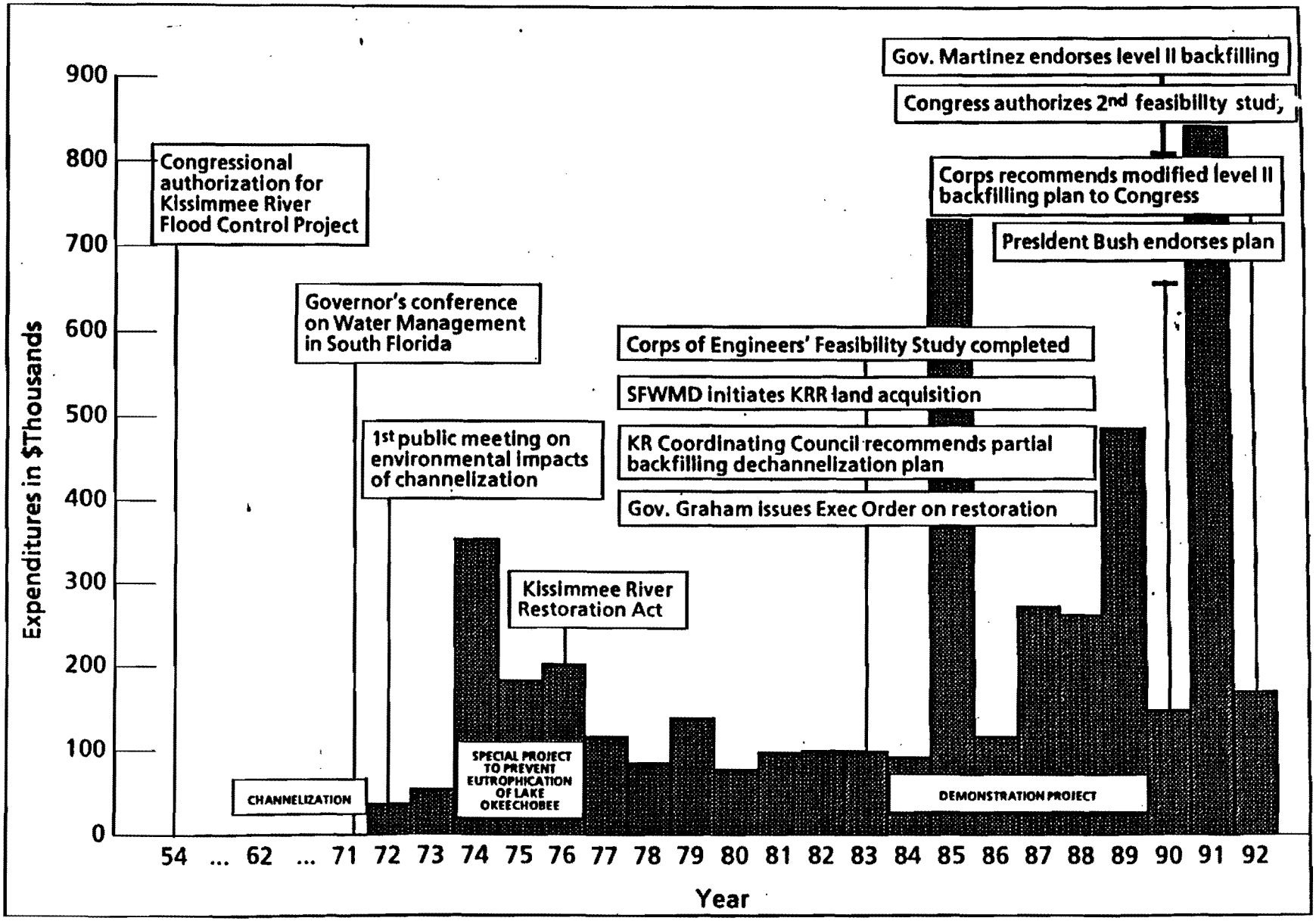


Figure 1. Kissimmee River Restoration Research Expenditures and Milestones

Kissimmee River Research Plan

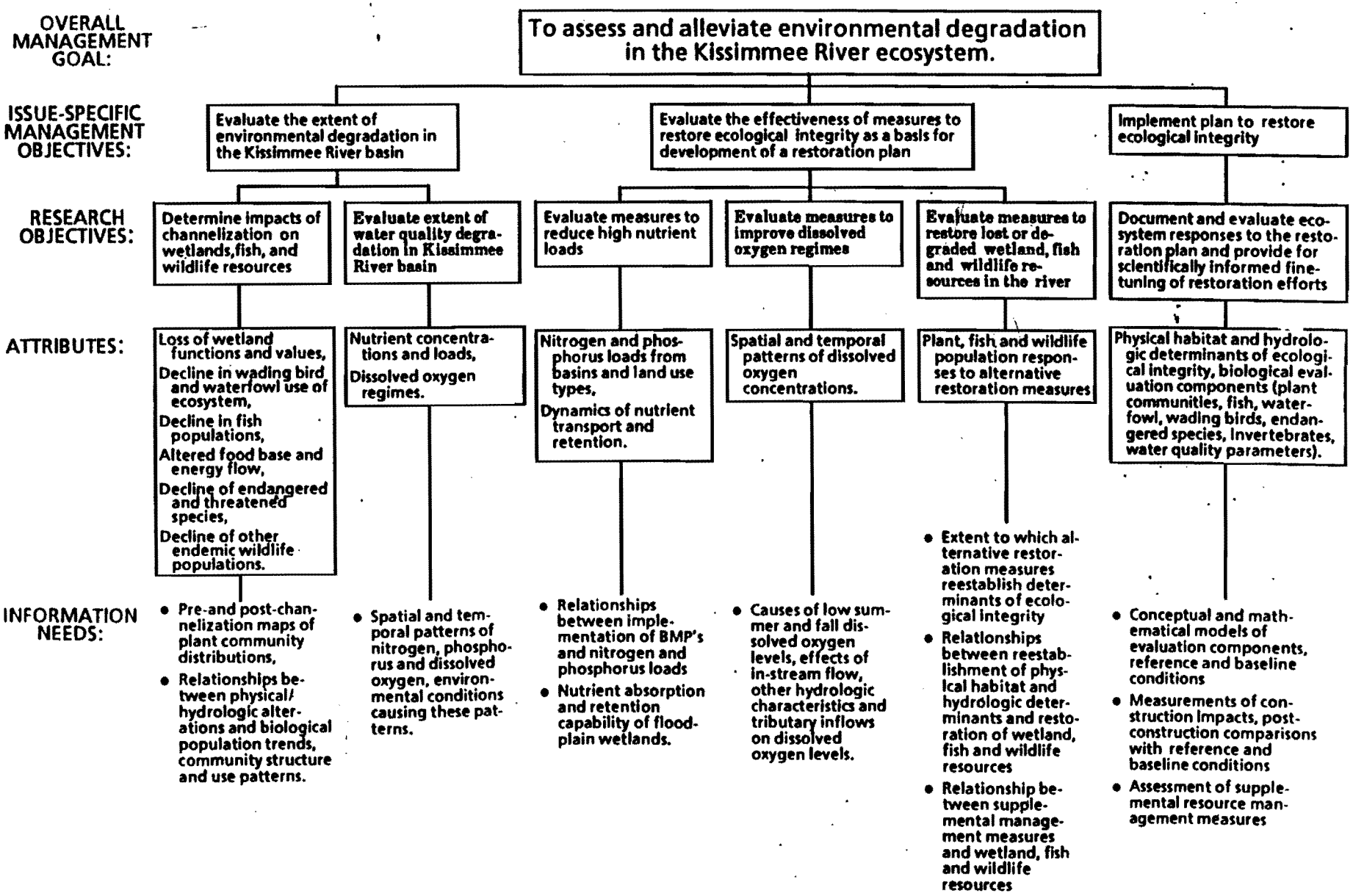


Figure 2. Kissimmee River Restoration Goal, Objectives, Attributes and Information Needs

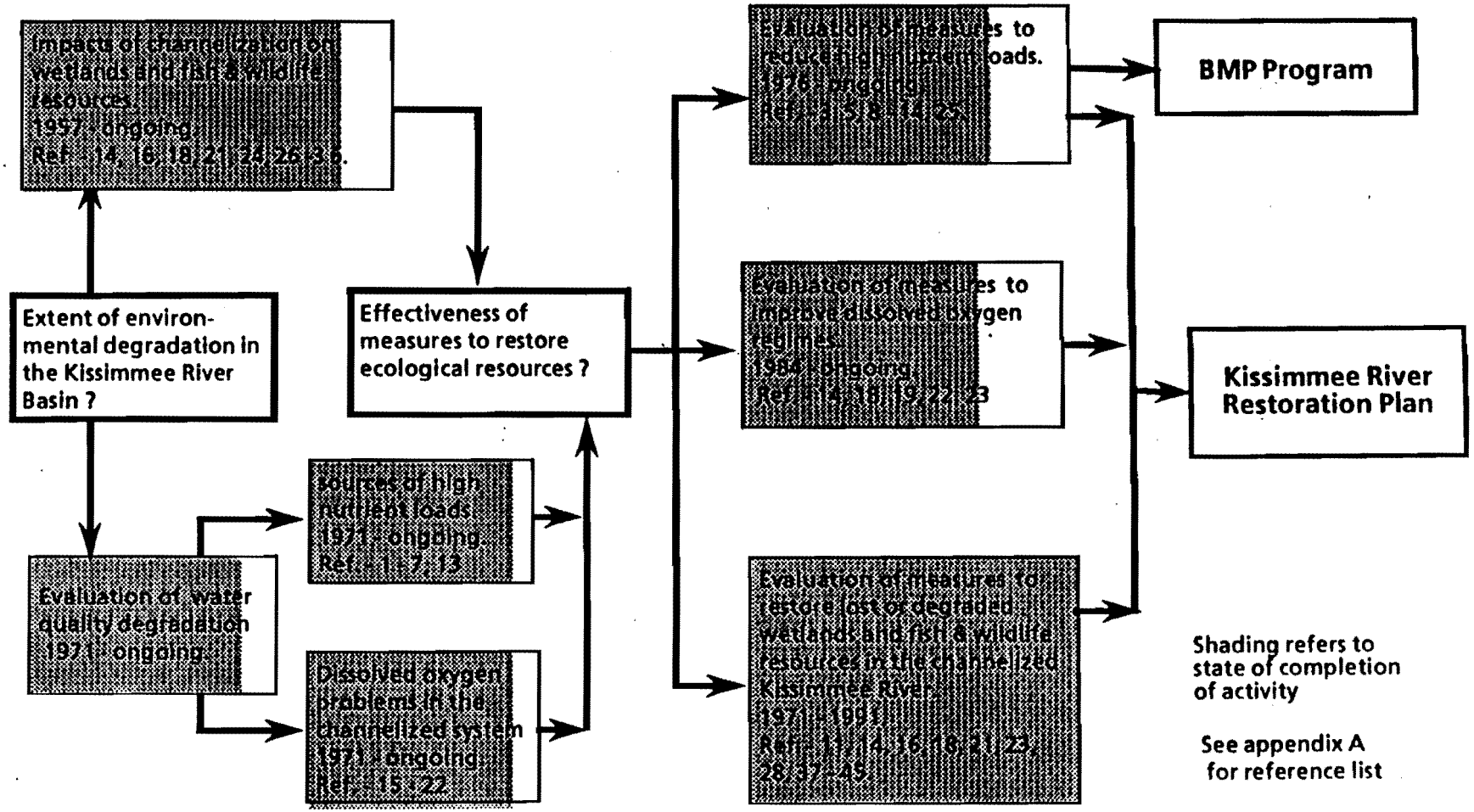


Figure 3. Research Questions

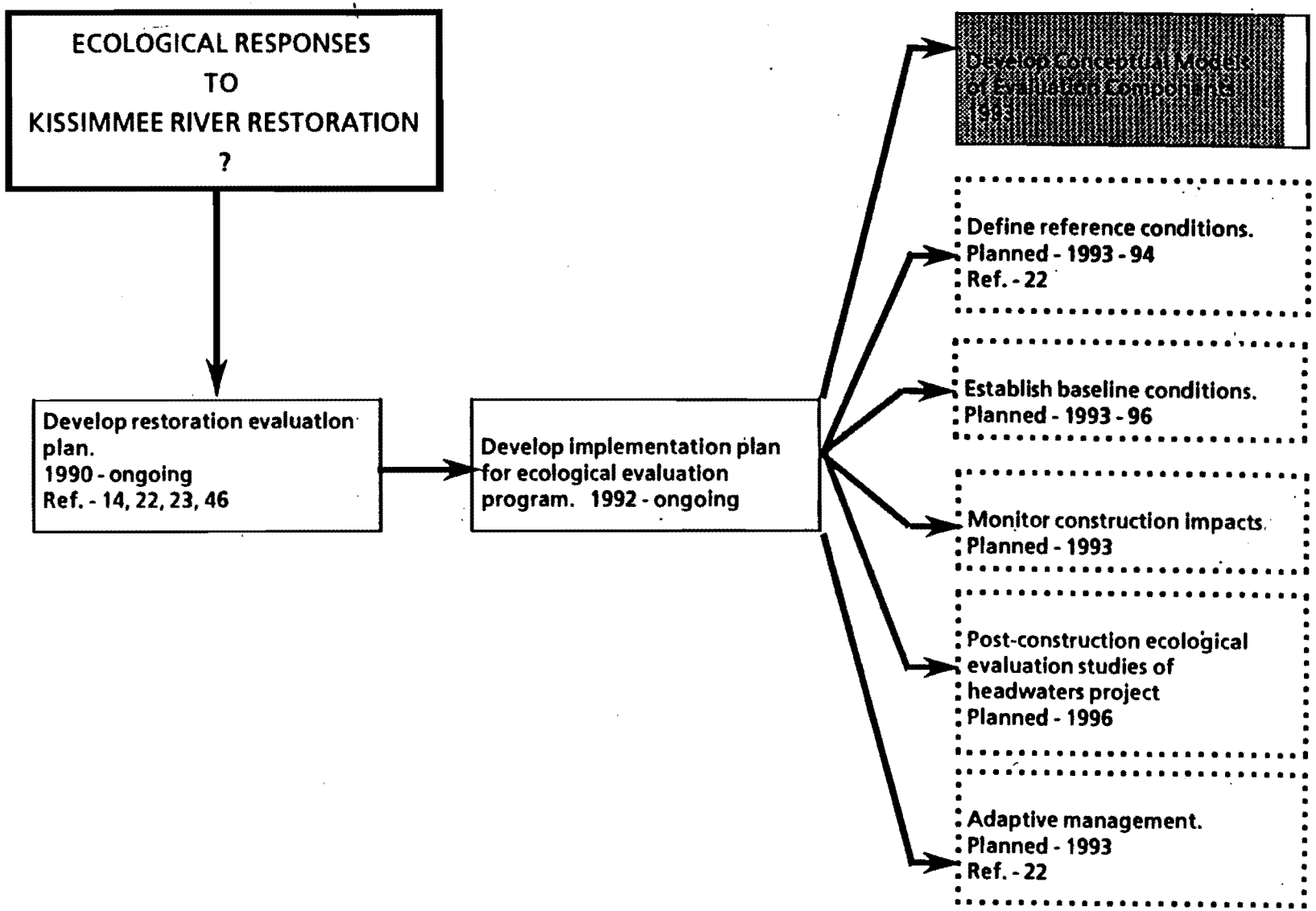


Figure 3. Research Questions

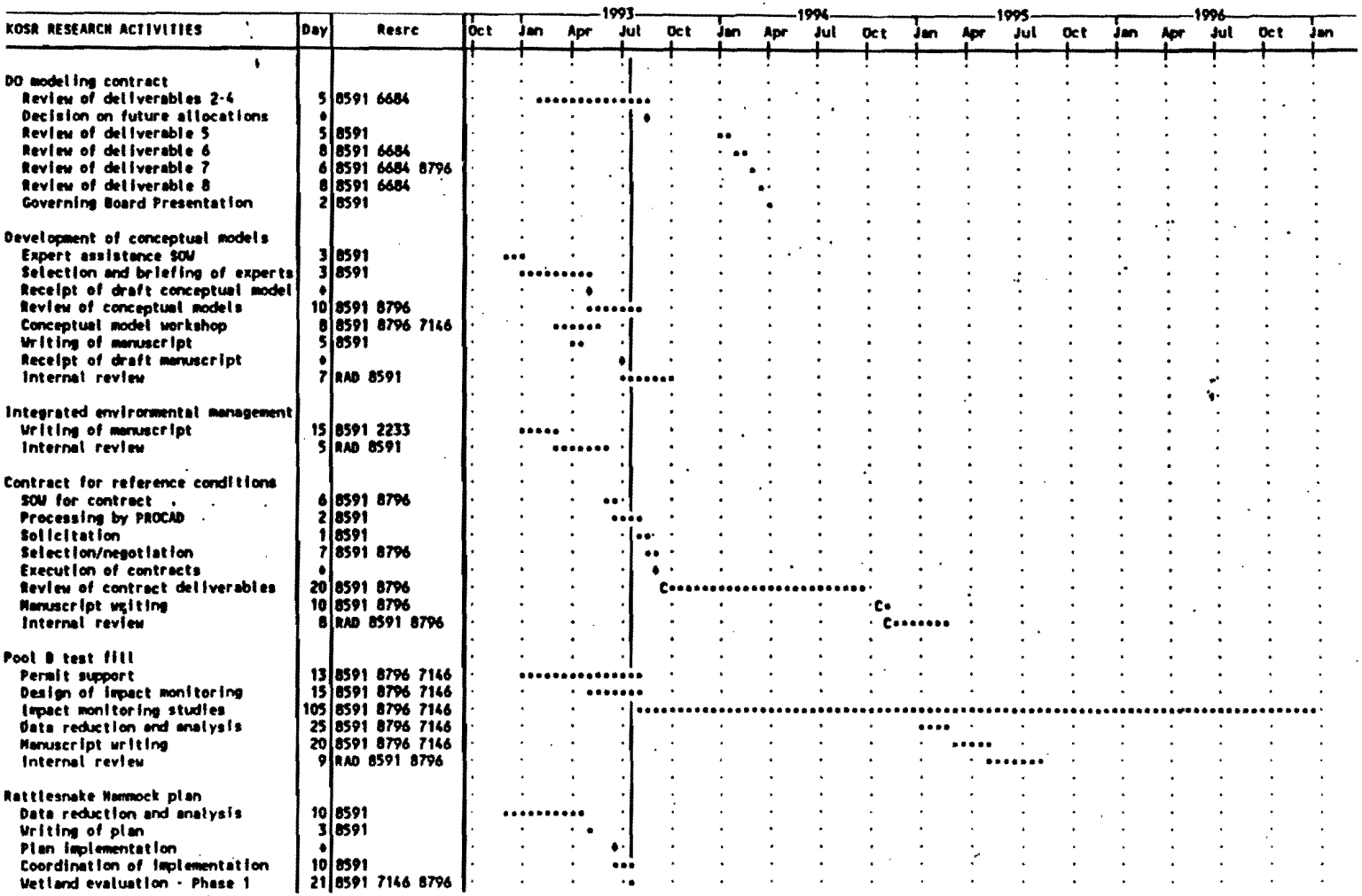


Figure 4. Gantt Chart. Time lines for KOSR Kissimmee River Research program tasks/activities. Days adjacent to activities are total number of days estimated for all staff combined to complete activity. Resource summary utilization chart (page 16).

Kissimmee River Research Plan

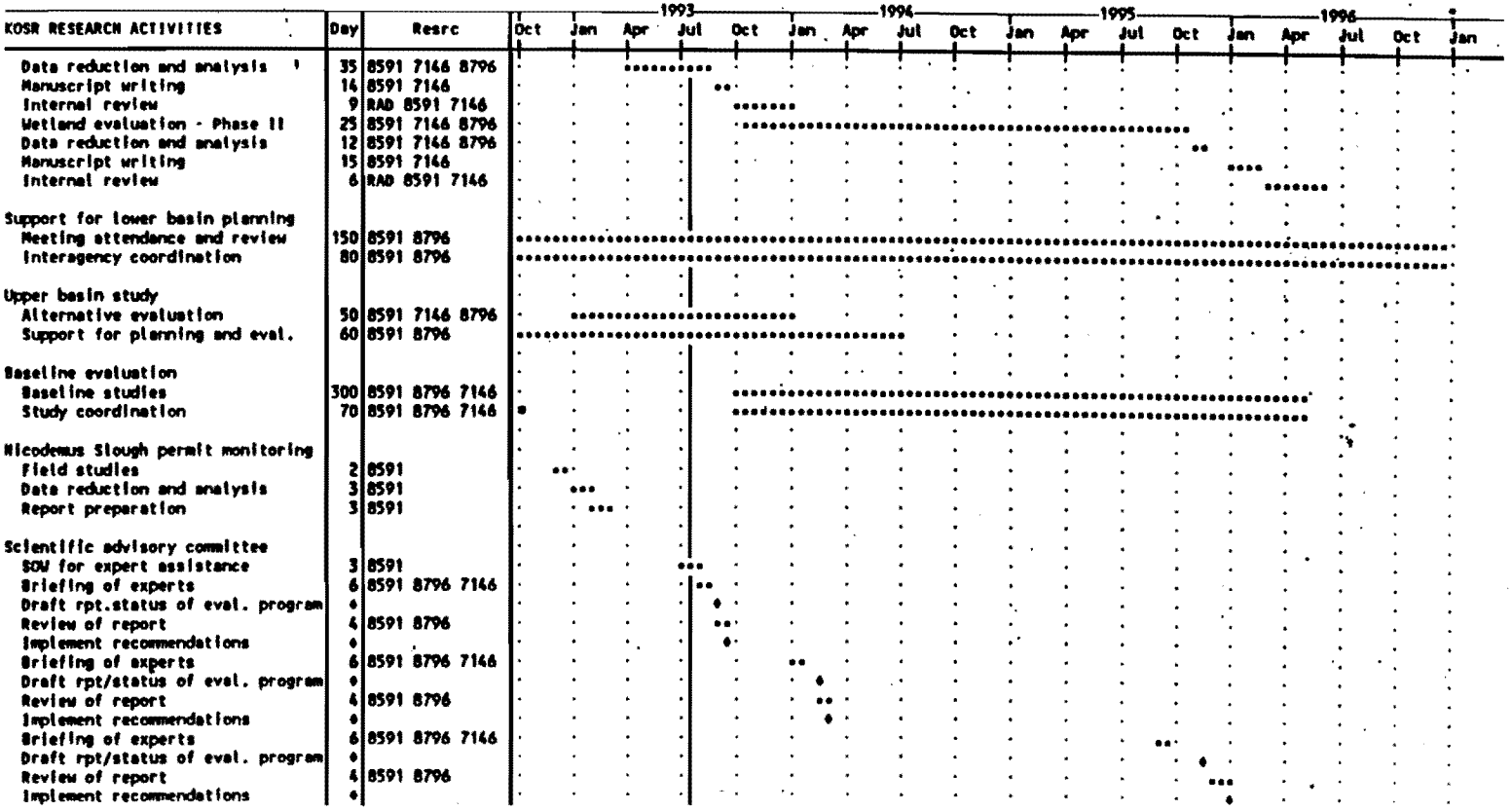


Figure 4 Continued Resource summary utilization chart provides KOSRD staff names associated with employee numbers, the number of days they are available for KOSRD program assignments per quarter, and the actual number of days per quarter an employee is currently assigned to Research activity. See legend for identification symbols.

Kissimmee River Research Plan

KOSR RESEARCH ACTIVITIES	Day	Resrc	1993 Oct	Jan	Apr	Jul	Oct	1994 Jan	Apr	Jul	Oct	1995 Jan	Apr	Jul	Oct	1996 Jan	Apr	Jul	Oct	Jan
Resource summary																				
Utilization																				
KATHLEEN KAUNERT	48.9	7006																		
ROBERT CHAMBERLAIN	48.9	4574																		
NETTIE WINOGRAD	48.9	4112																		
KAREN LYTHGOE	48.9	7820																		
MARK BRADY	48.9	0417																		
NICK AUMEN	45.6	2233			3.0															
TOM JAMES	48.9	5791																		
BRADLEY JONES	32.6	2351																		
DERA MUSZICK	48.9	5114																		
ERIC FLAIG	48.9	6263																		
TODD TISDALE	45.6	6684			2.0				8.0											
JOYCE ZHANG	48.9	1075																		
CHARLES HAMLON	48.9	2411																		
BARBARA BROWN	48.9	6864																		
AUBREY ARRINGTON	45.6	7146			10.4	22.6	28.3	30.9	30.6	19.5	19.2	18.3	25.8	8.6	8.5	11.5	18.5	2.3		
RESEARCH APPRAISAL DIVISION	65.2	RAD			0.7	1.3	1.9	2.1	0.0			1.0	1.1	1.4	0.7		0.6	1.4		
LOU TOTH	45.6	8591	25.2	64.8	60.2	72.9	57.5	59.9	36.9	27.3	30.9	23.1	17.1	13.9	10.5	13.5	2.3			
JOE KOEBEL	45.6	8796	18.6	28.7	41.2	47.6	53.7	56.3	37.3	32.0	37.0	35.2	21.7	14.4	13.5	6.5	2.3			
KARL HAVENS	45.6	5859																		
ROB SOSNOWSKI	45.6	3749																		
Total days			43.8	109.6	125.3	150.7	144.2	154.8	93.7	78.5	87.2	85.2	48.8	37.5	35.5	39.1	8.3			

Legend

▪▪▪▪▪	Activity	♦	Milestone
C▪▪▪▪	Activity on critical path	L▪▪▪▪	Locked activity
▪▪▪▪▪	Partially completed activity	═══	Completed activity
▲	Original start date	▼	Original end date
.....	Discontinuous activity	.....♦	Baselined milestone

Figure 4 Continued

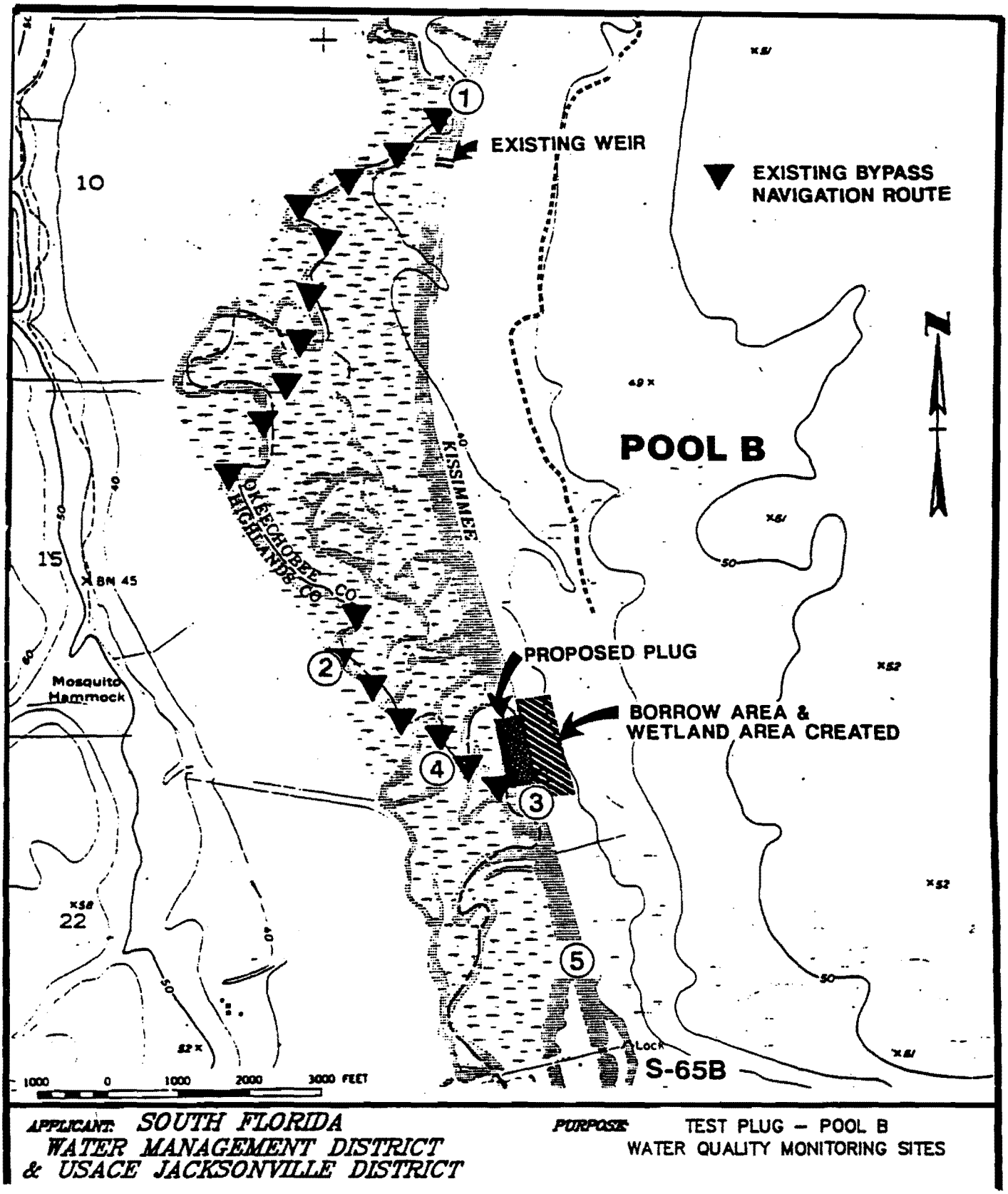


Figure 5. Test-Fill Water Quality and Vegetation Sampling Sites

SUBREGION 2:

LAKE OKEECHOBEE

BACKGROUND

Lake Okeechobee covering over 1732 km^2 is the "liquid heart" of the once contiguous Kissimmee/Lake Okeechobee/Everglades system. The lake has an average depth of approximately nine feet and occurs as a broad, shallow, bedrock depression. The lake provides flood protection by functioning as a storage basin, serves as a primary source of water for consumptive uses in South Florida, supports a valuable commercial and sport fishery, and provides critical habitat for fish and wildlife.

Drainage is derived from the Kissimmee River basin, Taylor Creek, Nubbin Slough, Nicodemus Slough, Fisheating Creek, Indian Prairie Canal, Harney Pond Canal, the Everglades Agricultural Area (EAA), Lake Istokpoga, and contiguous areas. The lake's largest outlets include the St. Lucie Canal eastward to the Atlantic Ocean and the Caloosahatchee Canal and River to Gulf of Mexico. The four major agricultural canals, West Palm Beach, Hillsboro, North New River, and Miami Canals drain to the south into the Everglades region.

MAJOR ISSUES

Physical, chemical, and biological attributes of the Lake and its tributaries and distributaries have been significantly altered since construction of the Central and Southern Florida Flood Control Project. The alterations have been brought about by changes in hydrology (timing, direction, route of flow, lake stage), increased nutrient and contaminant inputs, an introduction of exotic species of flora and fauna.

Prior to drainage, lake stage was controlled by rainfall and evapotranspiration; water quality was determined by basin geology; a large, dynamic, and heterogenous littoral zone existed along the Northwestern shore; and surface water outflows were southward via sheet flow to the northern Everglades. Currently, lake stage follows a regulation schedule designed to maximize storage capacity prior to the wet season and water availability during the dry season; the lake is considered to be highly eutrophic as a result of increased nutrient loading from agricultural and urban land in the drainage basin and backpumping of waters from the Everglades Agricultural Area; the extent and dynamics of the littoral zone are confined by the Herbert Hoover Dike; large areas dominated by *Typha*, *Panicum*, *Hydrilla*, or *Melaleuca* are found in the littoral zone; and surface outflows are via channelized connections to the estuaries and southeastern well fields.

PREVIOUS RESEARCH PLANS

A series of management and research plans have been developed for the lake in response to increasing concerns about water quality and supply. Four plans were reviewed prior to developing the restoration goals and research strategies outlined in this document. These include the Lake Okeechobee Technical Advisory Committee (LOTAC-I) report (LOTAC-I 1986), Lake Okeechobee Technical Advisory Council (LOTAC-II) final report (LOTAC-II 1990), Lake Okeechobee Surface Water Management and Improvement (SWIM) Plan (SFWMD 1993), and the Lake Okeechobee Research Plan (SFWMD 1993). An overview of the research and monitoring activities specific to water quality and environmental resources in each of the four documents follows.

Lake Okeechobee Technical Advisory Committee

In August, 1985, the Governor requested the Secretary of Florida Department of Environmental Regulation (DER) to take the lead in conducting a study of the conditions that affect water conservation and quality and biological characteristics of Lake Okeechobee. In response to this request, the secretary established the Lake Okeechobee Technical Advisory Committee (LOTAC-I). This committee reported phosphorus levels doubled in the lake over the period 1973-1984, the lake was losing its ability to assimilate phosphorus, and water supply demands stress available supply during periods of drought (LOTAC 1986). A list of management alternatives to reduce phosphorus loading by 40% and increase water supply were provided. LOTAC-I did not consider the potential impacts of nutrient diversion proposals upon other potential receiving systems. The committee recommended development and implementation of a coordinated monitoring and research plan with focus on phosphorus sources and dynamics, best management practices, downstream impacts of proposed diversions, the effects of lake levels on biological communities, and comprehensive fish surveys.

Lake Okeechobee Technical Advisory Council

The Lake Okeechobee Technical Advisory Council (LOTAC-II) was created by the Legislature through the Surface Water Improvement and Management (SWIM) Act of 1987 and was continued by Executive Order through March, 1990. The final goal of the LOTAC-II was to make findings and recommendations for permanently eliminating adverse environmental effects of past and proposed diversions of nutrient rich water from the lake.

Preliminary results of research projects undertaken in response to recommendations in the LOTAC-I report (LOTAC-I 1986) were presented to LOTAC-II and were used in making recommendations. The findings and recommendations for Lake Okeechobee focused on the draft interim SWIM plan (SWIM 1989) and included the completion and implementation of the SWIM Plan and the continuation of ongoing research efforts undertaken to address issues outlined in the 1986 LOTAC-1 report. In particular, LOTAC-II stressed the need for interpreting monitoring data (water quality) to determine relationships between climatological and hydrological events and the resultant runoff of phosphorus.

Surface Water Improvement and Management Plan

The Surface Water Improvement and Management (SWIM) Act was adopted by the Florida legislature in 1987. This law required the South Florida Water Management District (SFWMD) to: (1) implement the LOTAC-I recommendations except those that might have adverse impact elsewhere and (2) develop a SWIM plan for Lake Okeechobee to address point and nonpoint source pollution, destruction of natural systems, correction and prevention of surface water problems, and research for better management of surface waters and associated natural systems. The Lake Okeechobee SWIM Plan (SFWMD 1993) contains a series of goals, objectives, and strategies in seven categories (water quality, environmental resources, water supply, flood protection, recreation, navigation, and public information (Appendix I). Strategies specific to research and monitoring include:

(1) determine the extent to which Class I and Class III water quality standards are exceeded in lake and within all inflows and upstream tributaries to the lake.

(2) determine the phosphorus uptake capacity of lake sediments and identify key processes affecting its ability to assimilate and retain phosphorus.

(3) perform an assessment of current water quality trends within the lake and at all tributary inflows.

(4) update the Lake Okeechobee nutrient budget to reflect in-lake and tributary phosphorus loading trends and identify basins out of compliance with the phosphorus performance standard.

(5) identify and quantify nitrogen cycling, sources and sinks within the Lake Okeechobee watershed.

(6) develop appropriate nitrogen loading and concentration criteria for nitrogen inputs into the lake if necessary and appropriate.

(7) develop and maintain a quantitative data base to monitor long-term changes in the lake's biological communities (i.e. phytoplankton, invertebrates, fishes, macrophytic, and avian) in response to changing water quality and hydrological conditions.

(8) develop and implement management programs to enhance the native vegetation communities of the Lake Okeechobee littoral zone.

SFWMD Lake Okeechobee Research Plan

The Lake Okeechobee Research Plan (SFWMD 1993) defines a series of research objectives and information needs to support the overall goal to "protect and improve the water quality and ecosystem health of Lake Okeechobee". The Executive Summary of the Plan is appended (Appendix 1).

RESTORATION

Restoration of Lake Okeechobee is dependent upon the re-establishment of water quality, lake levels, and a littoral zone that will support a self-sustaining ecosystem. The key question is can hydrologic linkages between the Kissimmee River, Lake Okeechobee, and the Everglades be restored to a degree necessary to support a self-sustaining ecosystem, similar to the historic system, while providing flood protection, water supply, and a sustainable economic system.

The Science Sub-group developed a series of ecological and hydrological restoration objectives for the Lake. For each objective, information needs were identified and approaches designed to meet these information needs outlined.

Ecological Restoration Objectives

- Minimally, expand Lake Okeechobee's littoral zone by 200 sq km on the northwest side and allowing for increased water levels, and consequently hydrologically integrating the Lake and the Kissimmee River. Maximum restoration requires reestablishing the total lost littoral zone present prior to drainage and flood protection works.

- Integrate the islands at the southern end of the Lake into an overall management plan for the Lake

- Eliminate (maximum) or control (minimum) exotic species such as Melaleuca from Lake Okeechobee littoral zone.

- Reduce nutrient inputs to Lake Okeechobee to predisturbance levels; restore the lake's natural trophic status and phosphorus-limited condition; reduce algal bloom frequency, intensity, and composition to natural conditions.

- Eliminate (maximum) or reduce (minimum) point and nonpoint sources of pollution to Lake Okeechobee to meet Class I/III water quality standards.

- Restore Lake Okeechobee water quality, basin land use characteristics, and littoral zone to pre-disturbance conditions for enhancement of wading bird, waterfowl, and threatened/endangered populations.

- Establish and maintain a recreational and commercial fishery that is consistent with the natural water quality and biological productivity of a restored Lake Okeechobee.

*** All research questions and associated approaches were formulated under the assumption that a portion of the northwestern dike would be removed and the littoral zone would expand into this area.**

Research question: What will be the spatial extent and hydrologic character of the expanded littoral zone along the northwest shoreline?

Approach:

Prior to changing the configuration of the Northwest levee, the spatial extent and hydrology of the expanded littoral zone under the range of lake regulation schedules must be known. This information can be obtained by integrating proposed additions to the littoral zone into existing surface water models. The first step will be to conduct a grid based topographic survey in the area behind the existing levee. Using this information, expected water depths and hydroperiods over the entire littoral zone can be determined over a range of lake stage, rainfall, and routing scenarios.

Tasks: Conduct a grid-based topographic survey of NW area behind the Herbert Hoover Dike.

Incorporate this area into grid based spatial hydrologic models.

Integrate output from the hydrologic models into GIS databases.

Research question: What are the water quality impacts associated with changes lake stage and littoral zone configurations?

Approach: Water quality has been the major focus of research and monitoring efforts in Lake Okeechobee. Existing water quality monitoring efforts in the lake should be expanded to include the expanded littoral zone. Using the data from past and ongoing monitoring efforts, models of phosphorus transport from open water sediment to the littoral zone should be developed. Additional models of water movement and phosphorus transport over the range of lake stage and littoral zone configurations should be developed. Output from these models can be used to develop specific recommendations on the configuration and water delivery to an expanded littoral zone.

Tasks: Develop models of phosphorus transport from sediments in the open water to the littoral zone.

Develop hydrologic models to investigate the potential for nutrient input via lake water to areas in the existing littoral zone that are isolated from eutrophic water.

Research question: How will vegetative and animal communities respond in the expanded littoral zone?

Approach: Hydrology is the dominant forcing function on littoral zone vegetative and animal communities. Because of the diversity in the littoral communities a range of ecosystem attributes should be modeled and monitored. The sub-group recommends using, at a minimum, vegetation, game and nongame fish, wading birds, and snail kites as ecological endpoints in modeling and monitoring efforts. A GIS modeling and data management approach is the only feasible method of managing the data layers required.

Using output from the spatial hydrologic and nutrient transport models as templates, addition modules should be developed to investigate vegetative community types and their spatial distribution and dynamics that can be expected to develop in the expanded littoral zone. These models should be designed to incorporate management options such as lake stage regulation and prescribe fire.

Once hydrology and vegetation models are developed, additional models of the responses various animal communities to changes in configuration, extent, composition, and hydrology of the littoral zone should be developed. Again, these models can be used to investigate the impacts of various management actions on animal communities.

Once the expanded littoral zone is established, long-term monitoring of vegetative and animals communities should be conducted. This will provide basic information on relationships between forcing functions (hydrology, fire, drought, etc,) and response endpoints (vegetation, wading birds etc.). Statistical relationships between forcing functions and key ecosystem attributes can be refined. Long-term monitoring will also provide critical information to determine if the ecological restoration goals are being met. These monitoring programs should be integrated with those developed for other regions in the South Florida ecosystem. The Science-Sub groups recommends monitoring vegetation, fish (game and non-game), wading birds, and snail kites as part of an integrated approach to evaluate the success of restoring part of the littoral zone. These monitoring efforts will supplement the water quality and algal community monitoring programs outlined the Lake Okeechobee Research Plan (SFWMD 1993).

Tasks: Develop models of vegetative community response to hydrologic conditions in littoral zone.

Develop models of the responses of fish, wading birds, and snail kites to predicted hydrologic and vegetative conditions in the littoral zone.

Develop and implement long-term monitoring programs at the appropriate spatial and temporal scales for vegetation, fish, wading birds, and snail kites in the littoral zone.

Research question: What will be the impacts to the southern islands under different regulation schedules?

Approach: The approach would be the same as for the expanded littoral zone. Topographic data for the southern islands should be integrated into existing hydrologic models. The output from these models can be used to determine the potential impacts to these areas under different regulation schedules so as not to negatively impact these areas.

Tasks: Conduct a grid-based topographic survey of islands in SW.

Incorporate these islands into based spatial hydrologic and nutrient transport models.

Integrate output from the hydrologic models into GIS databases.

Research question: What are the impacts of exotic plants on the Lake Okeechobee system and how can these impacts be mitigated.

Approach: The first step is to determine the distribution of exotic plant species. Next, the relationships between lake stage, altered fire regime, water quality and the distribution/abundance of exotics should be determined via gradient analysis. This will provide information useful in understanding the mechanisms associated with dispersal, establishment, and maintenance of exotic plant communities.

A better understanding of the distribution and density patterns of exotic plants can also be used to predict potential impacts to fish and wildlife habitats. This will provide information needed to help develop a priority list for species to control.

The next step is to develop control mechanisms for those exotics that have the greatest impact on the system. Since the goal is to develop a sustainable system, the development and implementation of biological control mechanisms should be given top priority. For example, the SFWMD has ongoing projects to investigate bio-control mechanisms for Melaleuca and the relationships between hydroperiod on the growth of Melaleuca seedlings (SFWMD 1993).

Tasks: Map the distribution of exotic plant species.

Perform gradient analysis to determine controlling factors in the distribution and spread of exotics.

Develop a priority list of exotics to control.

Develop biologic control mechanisms for all exotic species.

Research question: Are exotic and native fish competing for resources?

Approach: The habitat and dietary requirements for exotic fish in Lake Okeechobee need to be determine over the range of life stages. This will allow the potential impacts to native species to be assessed.

Task: Conduct census surveys and feeding studies as necessary to assess resource partitioning between native and exotic fish.

Research question: What is the relative role of internal recycling vs. external loading in the development of phytoplankton blooms?

Approach: This question is being addressed comprehensively in the SFWMD Lake Okeechobee Research Plan. This task is intended to reaffirm the need for this information.

Task: Collect data and analyze trends (spatial and temporal) in nutrient concentration, nutrient loading, and bloom development, composition, and magnitude.

Research question: What is the response of the aquatic invertebrate community to the changes in water/sediment quality?

Approach: Analysis of the spatial and temporal trends in invertebrate community structure over the range of water/sediment quality conditions will provide information needed to assess impacts not only to invertebrates but also potential impacts to higher trophic levels. Existing chemical, physical, and biological data can be used to develop a stratified random sampling approach. This will allow rigorous statistical analysis to determine changes in invertebrate community structure and the causative factors.

Task: Collect data and perform gradient analysis on benthic invertebrate communities over the range of sediment type/quality.

Research question: What contaminants are likely to be impacting fish and wildlife communities?

Approach: A wide range of chemical contaminants have the potential to impact fish and wildlife communities in Lake Okeechobee. Due to the wide range of chemicals and effects, a systematic approach is needed

to address potential effects. First, a list of contaminants most likely to impact fish and wildlife in the lake needs to be developed. Once this is done, appropriate studies can be designed to address the magnitude and extent of the problem. This process should be part of a system-wide reconnaissance.

Tasks: Acquire data on local, regional, and global sources, transport mechanisms, fate, and effects and develop list of contaminants that warrant investigation.

Design appropriate monitoring programs (endpoints, methods etc.) to assess the extent and magnitude of impacts due to the contaminants of concern.

Hydrological Objectives

- Implement a more flexible regulation schedule that mimics natural hydrologic variability and enhances the expanded littoral zone ecosystem.

- Reestablish sheet-flow for all (maximum) or all regulatory (minimum) discharges from the southern portion of Lake Okeechobee to convey historic flows to the central and southern Everglades.

Research question: What is the system wide water budget on a yearly basis since levee construction?

Approach: The first step toward allocation and management of water on a system wide scale is to develop an accurate water budget. This will allow storage for flood control, the needs of consumptive users, and the requirements for a sustainable ecological system to be assessed on system wide basis.

Task: Acquire the necessary data to develop a system wide water budget.

Research question: What dynamic regulation schedule will better mimic natural hydrologic variability?

Approach: A natural systems type hydrologic model, incorporating the expanded littoral zone should be used to investigate water level fluctuation over a range of environmental conditions. Once this model is developed,

Tasks: Develop a "base" hydrologic model of lake stage that is coupled with inputs from the Kissimmee basin and rainfall.

Use the "base" model to investigate changes in lake stage associated with various restoration alternatives, including but not limited to: reduced east-west discharges, changes in agricultural /urban water demands, interbasin transfer of water from the Caloosahatchee urban areas into the lake, and changes levee configuration.

Research question: What are the potential impacts to the levee (structure, integrity, leakage) as a result of changes in regulation schedule.

Approach: Perform engineering studies as required.

Research question: What will be the "ecological" consequences associated with changes in regulation schedule?

Approach: A family of models to assess potential impacts to vegetation, fish, wading birds, and snail kites resulting from changes in lake stage.

Research question: What are alternative water delivery mechanisms to create littoral zone on the NW end of Lake Okeechobee? (ex. Reconfigure Paradise Run)

Approach: Develop models of various water delivery scenarios.

Research question: What is the feasibility of conveying predrainage flows from Lake Okeechobee south to the Everglades?

Approach and Task: Investigate the use of both operational methods and structural modifications (i.e., enlargement of maximum conveyance capacity in channels and pumps) to eliminate the regulatory releases from Lake Okeechobee to the St. Lucie and Caloosahatchee canals and substantially increase the delivery of water from Lake Okeechobee to the Water Conservation Areas.

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APPENDIX 1

LAKE OKEECHOBEE RESEARCH PLAN

LAKE OKEECHOBEE RESEARCH PLAN EXECUTIVE SUMMARY

The Lake Okeechobee Research Plan (LORP) defines a series of management objectives and research activities for Lake Okeechobee, identifies information requirements and provides an initial framework for decision analysis.

For the next year the majority of effort by the Kissimmee and Okeechobee Systems Research Division (KOSRD) will be to complete the analysis and publication of research and monitoring efforts that have been undertaken to date. Future research directions will be based on analysis, integration, publication, and recommendations from past studies. No new research initiatives, in-house or contractual, will be initiated during the next year without the existence of a compelling need.

The research plan was developed with input from many individuals involved with research and monitoring of Lake Okeechobee, including the Lake Okeechobee Task Force, and is based on the following philosophy:

- Use external, peer-reviewed publications as the primary outlet for disseminating information
- Emphasize well-designed, experimental research to address management questions
- Phrase past history and future plans using resource management objectives
- Indicate key results of past research
- Indicate status of research (completed or in progress)
- Recognize that the research plan is a living document and will be revised annually.

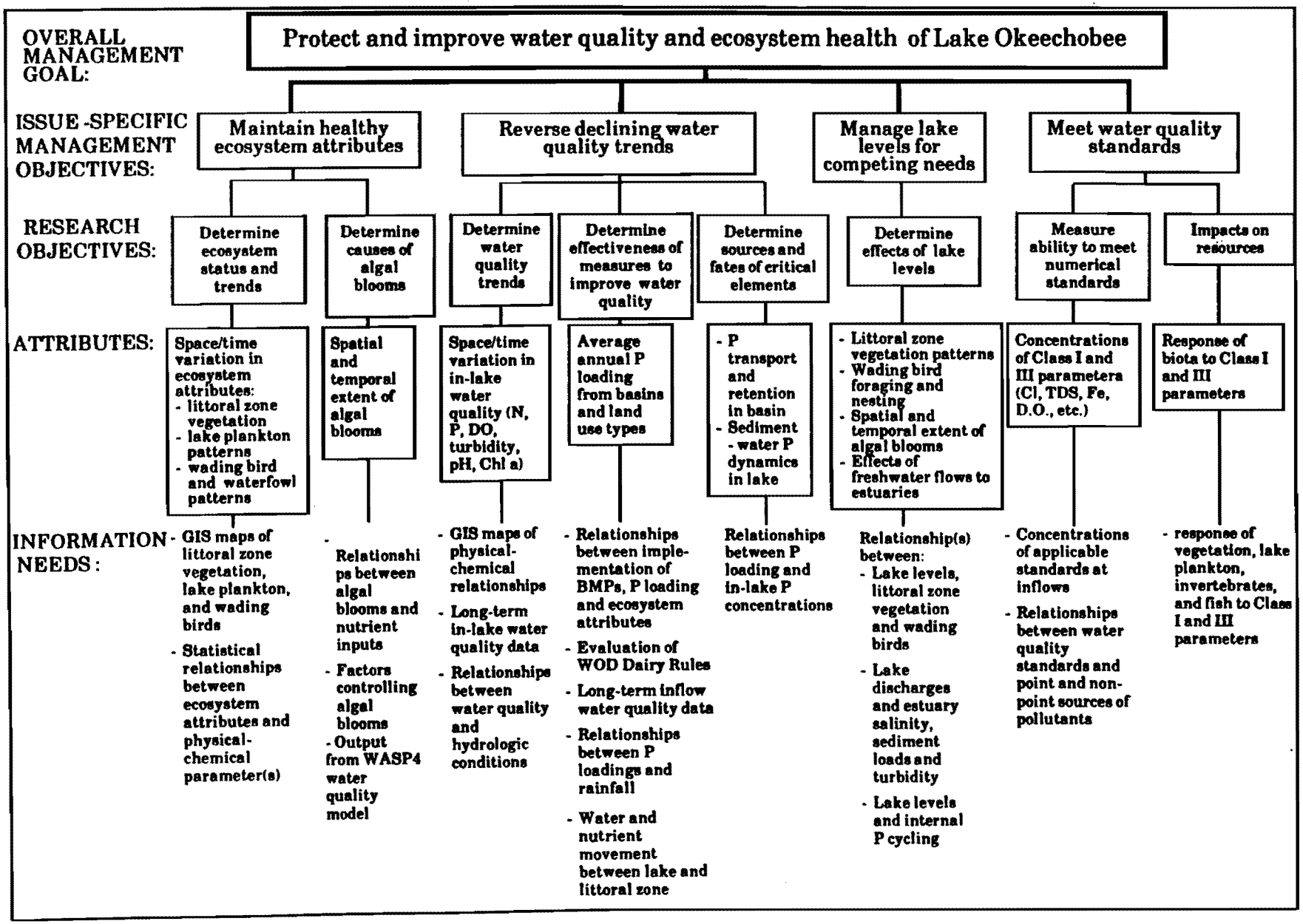
The research plan consists of a chronology of Lake Okeechobee research milestones and huistorical funding levels. **Figure 3** illustrates the overall research objectives hierarchy for Lake Okeechobee, including seven research objectives, with their accompanying attributes and information needs . Each of the resource management objectives is then described in greater detail in the plan, indicating subject relations, time frames and references to specific research projects.

MAJOR OBJECTIVES

The seven major Lake Okeechobee research objectives are summarized as follows:

Determine Ecosystem Status and Trends. LOTAC I and II recommended an increased level of research on the Lake Okeechobee to better understand ecosystem structure and function. An important part of this effort is the measurement and documentation of the current status of the ecosystem to provide a foundation for the long-term assessment of potential changes and to create a knowledgeable basis for selecting management strategies. Lake Okeechobee proper encompasses a large area (750 sq miles) and is composed of several ecological regions (a marsh zone and as many as five functionally distinct open-water zones). Because of this diversity, research and monitoring is required of a wide range of attributes.

Figure 3. Lake Okeechobee Research Objectives, Attributes, and Information Needs



Determine Causes of Algal Blooms. Algal blooms are a relatively common occurrence in Lake Okeechobee during the summer months and are a source of public concern. Blooms, which normally do not represent a public health threat, can cause aesthetic problems such as visual mat formation and noticeable deterioration of drinking water taste and odor. Severe blooms have the potential to cause fish kills. Research and historical accounts suggest that Lake Okeechobee experienced algal blooms prior to human influence, but it is possible that human-induced inputs of nutrients have increased the frequency and intensity of blooms. In order to address management options designed to reduce algal blooms, the spatial and temporal extent of blooms must be documented.

Determine Water Quality Trends. Lake Okeechobee water quality has been the major focus of monitoring and research efforts since the late 1960s. Declining water quality trends have been a source of concern and have led to regulations designed to reduce the inflow of nutrients, particularly phosphorus, to the lake. Increasing phosphorus concentrations are evident, especially over the last 20 years. The largest source of phosphorus enrichment is agricultural activities north of the lake, and research and demonstration projects were implemented to reduce that enrichment. Concentrations of nutrients in the lake water and sediment are important to the entire lake biological community, and the health of the ecosystem depends on management activities designed to reverse declining water quality trends.

Determine Effectiveness of Measures to Improve Water Quality. Declining water quality trends discussed in Section III above led to the establishment of regulations designed to regulate the input of phosphorus into the lake. Phosphorus was deemed to be the most important water quality parameter relative to declining ecosystem health, and was the most likely to respond to alterations in land management practices. The largest source of external phosphorus loading was determined to be dairy activities north of the lake, and the Dairy Rule and the Works of the District Rule were implemented to reduce this source. Best management practices (BMPs) were designed and implemented on individual dairies, along with a dairy buy-out program, to improve Lake Okeechobee water quality. A modified Vollenweider model was utilized to establish a target loading reduction of 40%.

Determine Sources and Fates of Critical Elements. A thorough understanding of nutrient cycles, both in the basin and in the lake, is necessary in the analysis of water quality trends and BMP effectiveness. Nutrients such as nitrogen and phosphorus can undergo a series of transformations between chemical forms that affect their biological availability. Storage of nutrients in unavailable chemical forms or in locations that are unavailable to the biological community must be considered. A particularly important question relative to the reduction of phosphorus in inflows is the potential long-term contribution of stored sediment phosphorus to water column phosphorus. It is possible that reductions in external phosphorus loading could be offset by internal phosphorus loading from the lake bottom.

Determine Effects of Lake Levels. Regulation of Lake Okeechobee's water level represents one of the most viable management options available to influence ecosystem health. However, Lake Okeechobee's water level is regulated for a variety of reasons, most of which are in competition with one another. Lake levels must be maintained high enough to provide sufficient water supply during times of drought, low enough to provide flood protection in the event of catastrophic winds and rain, and at the proper level to enhance the in-lake and littoral zone biological communities. Other considerations include the effect of lake discharges on estuarine communities, and on water supply to the Everglades. Preliminary

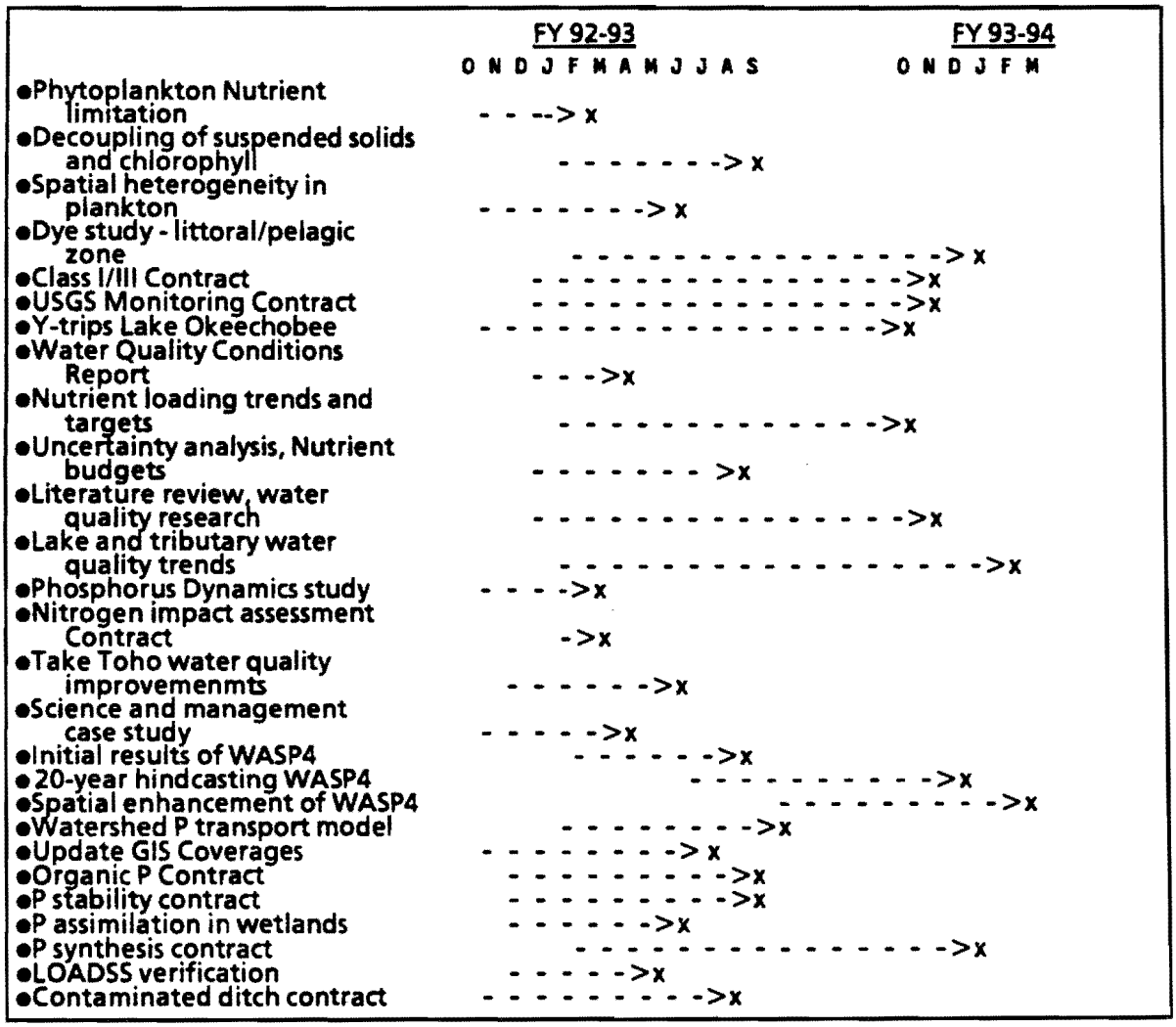
information from the Lake Okeechobee Ecosystem Study indicates that higher lake levels have been detrimental to littoral zone vegetation and to wading bird populations.

Measure Parameters related to Numerical Water Quality Standards. Because Lake Okeechobee is utilized as a drinking water source and for human-contact recreational activity, its waters must comply with Class I and III water quality standards.

KNOWLEDGE ACQUISITION TIMEFRAMES AND SUPPORT REQUIREMENTS

Study plans have been developed to conduct research, modeling, and monitoring activites that will address the six management objectives. The Lake Okeechobee research plan provides details of proposed research, flow charts of existing and required information and estimated resources needed to accomplish these efforts. The major knowledge gained from the research conducted, and the time course over which it is gained is outlined in Table 7.

Table 7. Knowledge Gained from the Lake Okeechobee Research Plan



SUBREGION 3:

UPPER EAST COAST-ST. LUCIE RIVER AREA

INTRODUCTION

The upper east coast of the South Florida Ecosystem restoration project study area includes St. Lucie County, Martin County, and the northern part of Palm Beach County. The physiography of the area is dominated by a ridge-and-swale, terrace-and-bar topography created by a sequence of Pleistocene marine transgressive episodes (Parker et al. 1955). This geologic history has created both the terraced structure of the land, the physiognomy of the river valleys, and the extensive lagoons--the Indian River Lagoon System and Lake Worth--characteristic of the coastal zone in this region.

The Atlantic Coastal Ridge is the most densely settled physiographic zone both here and to the south, with the barrier islands of the Atlantic Beach Ridge alternating between relatively protected park lands and extensive development--most notably in Palm Beach. The natural watersheds of watercourses in the region--including the St. Lucie River and the Loxahatchee--are largely defined by relict dune lines and eroded marine terraces, albeit much modified by canals and drainage.

The coastal lagoons are locally regarded as an important estuarine resource of aesthetic, economic, recreational, and biological value. Prior to drainage and development, however, these lagoons were more isolated from the Atlantic Ocean, and received fresh water inflow in a pattern very different from today's.

Prior to about 1880, the entire Indian River Lagoon was connected to the Atlantic by perhaps only three natural inlets: Ponce de Leon (near New Smyrna Beach), Fort Pierce, and Jupiter. The Fort Pierce inlet, then located about four miles north of today's constructed inlet, apparently underwent a periodic shift from the mouth of the Sebastian River south to the vicinity of Fort Pierce. In 1880, the St. Lucie River, as a defining example, was very different from today's estuarine system. The St. Lucie was then a freshwater system discharging into the southern end of Indian River Lagoon, with its closest connection to the Atlantic some 25 miles to the north at the natural Ft. Pierce inlet. In 1892, the first artificial St. Lucie inlet was opened, restoring a local connection to the Atlantic that had not been a feature of the system since the early 1800s. This began a transformation (or restoration, depending on the breadth of historical perspective employed) of the St. Lucie from a freshwater to an estuarine system.

The picture that emerges for all the Atlantic coastal lagoons (Mosquito, Banana River, Indian River, and Lake Worth) is thus one of ecosystems undergoing long-period shifts (at the present sea-level stand) between estuarine and freshwater character. Only perhaps three to five inlets could be sustained at any one time from tidal exchange energies and freshwater scour. These inlets were constantly shoaling and migrating along the coast, creating new interior freshwater flow paths along the north-south axis and depositing sediment to build deltaic "narrows" in the lagoons. At times the lagoons have been entirely fresh: Lake Worth was first noted on an 1830 map as a freshwater lake with drainage from a swampy area along its western edge (Pierce 1970); both its present Atlantic inlets are artificial (Palm Beach County DERM 1990).

The opening of each artificial inlet robbed transport energy from the others. For example, when St. Lucie Inlet was dug and stabilized to keep it open, the natural Ft. Pierce inlet shoaled and closed; Ft. Pierce Inlet was reconstructed in its present location in the 1920s. In the Pecks Lake area between Jupiter and St. Lucie Inlets, additional inlets have continued to open and close, most recently in 1943 and 1962. The 1962 opening was closed by U.S. Army Corps of Engineers because of the shoaling problems it caused at St. Lucie Inlet. In sum, all the inlets in the system are now artificially stabilized and must be maintained by periodic dredging.

The construction of the Atlantic Intracoastal Waterway (AIW), designed to provide safe passage to water-borne transport from Maine to Key West, further modified the hydraulics of these lagoons. The AIW is a deep-water (4 m) dredged channel in an otherwise shallow (1-2 m) system. It acts both as a sediment trap and as a conduit for penetration of more saline (denser) ocean water into the lagoons. Additional hydraulic modification--in the form of reduced longitudinal transport--was introduced by the construction of access roads between the mainland and the barrier islands. The first bridges were of wood, constructed on pilings, and had little effect on circulation in the lagoons. These were replaced by fill causeways, pierced by narrow openings spanned by drawbridges, splitting the lagoons into hydraulically isolated sections. As drawbridges are replaced with fixed high-rise bridges, some of the problems are being corrected, both by widening of the central spans and by the construction of gaps in the causeways, spanned by "relief bridges," near their landward ends.

The terrestrial hydrology of the area has been affected by drainage works for agricultural and residential development, flood control, and water supply. The primary canals are the C-23, C-24, C-25 system in St. Lucie and Martin Counties, C-44 (the St. Lucie Canal, connecting Lake Okeechobee to the Atlantic), the C-18 complex in the Loxahatchee basin, and C-51 (the West Palm Beach Canal), which discharges into Lake Worth. Because of the seasonality of rainfall and the low-relief terrain, drainage works typically shorten and sharpen the hydroperiod, here as elsewhere in South Florida. Much of the area has been developed for citrus culture and range and pasture land, to a total of some 184,000 acres in the combined C-23, C-24 and C-25 basins. Of these, 82,000 acres (46%) require irrigation water.

As development has proceeded, conflicting water resource demands have become steadily more sharply contested. Several resulting actions have begun the process of resolving water allocation and management conflicts. The impacts of C-44 regulatory releases from Lake Okeechobee on the St. Lucie estuary have been ameliorated somewhat by the institution of the Run 25 regulation schedule (Trimble and Marban 1988). The need to protect the West Palm Beach urban well field recharge zone and the Loxahatchee Wild and Scenic River watershed has encouraged reclamation of Hungryland Slough and more sophisticated management of the C-18 Canal complex in the southern Loxahatchee basin. (South of C-18, the Biscayne Aquifer is the primary water source for Palm Beach County.) If concerns about quick-response flood water removal capacity can be resolved, water levels in the C-23-24-25 canals might be held at higher stages, in an apparent consensus decision that the environmental harm done by lowered water tables seems to outweigh their incremental contribution to effective flood protection. The Save Our Rivers (SOR) program has purchased (1986) the DuPuis Reserve (David 1991), and has included a variety of area lands in the SOR planning process. A notable feature of this sequence of purchases is the potential systematic restoration of hydrologic and habitat continuity in the Loxahatchee watershed, to include the DuPuis Reserve, the Corbett Wildlife Management Area, Pal-Mar, Loxahatchee Slough and Reserve, and the West Palm Beach water catchment area. The inclusion of natural water quality restoration zones at the western end of C-51, as provided in recent State legislation, will begin to address the impacts of C-51 on Lake Worth.

Fundamental problems remain to be solved, however, despite the growing dialogue among agricultural, natural resource management, residential development, and governmental institutions in the area. As elsewhere in South Florida, a lack of adequate tools and knowledge for evaluating the ecological, economic, and social consequences of water management alternatives is the most important impediment to consensus and action for achieving a sustainable future for the area. One aspect of the problem is unique to this area, however. The ecological future envisioned for these Atlantic coastal lagoons is that of a stable estuarine system, rather than the historical pattern of alternating freshwater aquatic and maritime regimes. The hydrologic management puzzle in this region is thus an ecosystem design challenge, rather than simply a resource allocation problem.

One primary objective in the redesign of this landscape is to foster the creation of healthy estuarine lagoons by restoring freshwater base flows and eliminating massive peak flood-control flows to the system. The best mixture of landscape alterations to achieve this end is far from obvious. Raising canal stages benefits wetlands and increases landscape detention and base flow. Issues then arise of impacts on agricultural productivity (which differ among uses, e.g., citrus vs. pasture) and loss of flood control capacity. Detention storage--the capacity of the landscape to hold rainfall on and near the surface, and release it over an extended period--was once an intrinsic property of

the low-relief terrain in this historical hydric landscape. This function can be partially restored in today's mesic landscape by building Regional Attenuation Facilities (RAF), i.e., constructed reservoirs, and their smaller analogues (Small Attenuation Facilities, SAF) spread throughout the drainage network. It has been proposed that the C-23-24-25 canal complex be physically connected to Lake Okeechobee, drawing upon the Lake's capacity as a regional reservoir or ultimate RAF. In this circumstance, waters that would otherwise be discharged to tide could in principle be metered to the restored wetlands of the Loxahatchee and other wetland complexes, thus rebuilding a significant portion of the natural hydrologic function of the region. Each of these options--RAFs, SAFs, canal water level management, and the proposed connection to Lake Okeechobee--has been the subject of recent research and feasibility studies (Spyke 1994, personal communication). Whether Lake Okeechobee could serve such a role without harm to itself is not apparent; this issue should be addressed in the context of research on the restoration ecology of the Lake ecosystem.

Current Water Management District rules (both SFWMD and SJRWMD) require SAF installation on new urban and agricultural projects. This policy avoids exacerbating the current problem, and may be providing some incremental improvements. Structures have been added to canals to increase water levels, improving water supply and increasing detention flows from storage in the shallow ground water.

These changes cannot fully compensate for the loss of wetland structure that has already occurred as the region developed, however, and "retrofitting" every parcel of land in the region is not a feasible alternative. Thus, RAFs, and access to storage capacity in Lake Okeechobee (with the caveat that the ability of the Lake to accommodate this usage is unproven), appear to be necessary additions to current approaches to restoring regional hydrologic function. In one proposal, a large RAF would be built at the western end of C-23 or C-24 and connected to Lake Okeechobee; this RAF would serve as a detention basin and as a water quality improvement facility to ensure that nutrient or pollutant loads are not imposed on the Lake as a cost of restoration of the coastal lagoons and intervening wetlands.

RESEARCH NEEDS

Sources of fine-grained organic sediments

Water and sediment quality in the coastal lagoons and estuaries is viewed as problematic due to the accumulation of significant deposits of fine-grained organic ooze on the bottom at many localities. Some of these deposits carry significant contaminant loads (Trefry et al. 1992, Trocine and Trefry 1993, Vereecke 1993). Although a variety of proposals to deal with the problem have been investigated, no action can currently be undertaken in full confidence of improving the situation, due to a lack of adequate understanding of the source and transport dynamics of the materials. Some of the deposits appear to be of considerable age, although whether deposited as mobilized terrigenous materials from canal construction or from recent activity in the watersheds is uncertain. Research needs to be undertaken to identify the source of the material (aquatic plants derived directly from the canals, dissolved organics of wetland origin precipitating at the salt interface, canal bank and construction debris, etc.), and the conditions driving transport and deposition, to better plan control measures.

Three-dimensional regional hydrologic model

This research project would constitute one thread of a spatial decision-support capability needed to begin a process of multi-institutional planning for regional landscape management. It would be based in hydrologic modeling of the surface and ground water resources of the region. Its capabilities and data needs include, inter alia,

- complete, and accurate, regional water budgeting;
- accurate flood and discharge profiles for canals and structures in the region, including a capability to evaluate the consequences of structure modifications;

- capability to evaluate impact of current and proposed secondary structures (e.g., weirs in feeder canals);
- ground water recharge and withdrawal scheduling;
- ability to accept weather service forecast and stage monitoring data, and respond with appropriate infrastructure operations schedules, and
- ability to track actual response (stage, discharge, water quality data) to continually recalibrate empirical and process-based response functions--for both quantity and quality parameters, including turbidity, dissolved oxygen, nutrient loads, and industrial, domestic, and agricultural toxic substances loadings.

One of the critical design criteria for this modeling system would be that it assist in the placement and operation of RAFs, SAFs, canal structures, hydrologic exchanges with Lake Okeechobee, and water releases to support ecological and economic functions of the regional landscape. Although current and developing policies in the region are certainly "directionally correct," the inability to evaluate the full costs and benefits of alternative scenarios impedes the consummation of the political and economic consensus needed to move forward with restoration.

Hydrodynamic models

Hydrodynamic models of the lagoons are needed to understand and forecast the effects of hydrologic management on water quality, the salinity regime, sediment quality and deposition, turbidity and color, and circulation. The permanent linkage of the lagoons to the Atlantic mandates specific investigations of flow on the shelf and net transport in the inlets, in order to understand larval transport and water quality interactions between the lagoons and the open ocean. In addition, the hydrodynamics of the entire lagoon cross-section--i.e., the AIW and the shallow margins--needs investigation and model building.

The resulting model systems can be used to forecast the effects of hydrologic manipulations on the lagoons. Once confidence in the models is gained, they can be used to evaluate possible engineering changes in the design and maintenance of the inlets that could improve water quality, benthic sediment quality, habitat condition, and ecosystem health in the lagoons.

Ecological response models

Ecological response models, linked to the hydrologic, water quality, and hydrodynamic models, are needed to forecast biological responses to hydrologic management alternatives. In addition to the general capabilities envisioned for the Restoration Project as a whole, ecological resource management needs for this region might include evaluation of salinity intrusion impacts on freshwater swamp forests, modeling of the response of specific target populations (e.g., oysters) to estuarine salinity regimes (Haunert and Startzman 1980, Haunert and Startzman 1985, *Appendix I: Draft St. Lucie Estuary Watershed Plan* in Steward et al. 1993), and management strategies for mosquito impoundments to enhance nursery functions for estuarine-dependent marine fauna and habitat value for bird populations.

Landscape planning and forecasting models

The coherence and reliability of regional planning, conservation, and development efforts would be immensely enhanced by the creation of a genuine landscape modeling capability for the Upper East Coast watersheds. The region is an intricate landscape mosaic of wetland complexes, residential, industrial and commercial development, park lands, and agricultural land uses in close proximity, with sometimes conflicting hydrologic and land management requirements. Formulation of consensus goals for a sustainable future will not succeed until all stakeholders can achieve reasonable certainty of adequate representation of their constituents' interests in the future

landscapes of the region. Landscape planning models should be developed with a capacity to reliably forecast natural resource, ecological, economic, and social consequences of engineering works, land use changes, and hydrologic management policies in the region.

Red mangrove culture

The red mangrove (*Rhizophora mangle*) has been artificially propagated in the lagoons, and is a valuable contributor to the detrital food chain. Its adult height impairs the customary scenic visibility of waterfront property on the lagoons, however, and property owners are legally entitled to prune the trees. The impact of pruning on the vegetation has not been fully evaluated, although the frost intolerance of this species suggests that it may be only moderately tolerant of mechanical damage. Tolerance for pruning damage and horticultural procedures need to be established.

CURRENT STUDIES

Because much of the study area is included in the Indian River Lagoon National Estuary Program (IRL-NEP), a substantial research planning and coordination effort is already underway. In addition, the IRL is the subject of SWIM planning coordinated between the South Florida and St. John's River Water Management Districts. An inventory of research and management studies begun prior to July, 1987, was published in the *Interim SWIM Plan for the Indian River Lagoon* (August, 1988) and *Indian River Lagoon Joint Reconnaissance Report* (Steward and VanArman 1987). A second survey of studies conducted between July 1987 and 1990 is given in Appendix C of the 1989 *Indian River Lagoon SWIM Plan*, and a description of studies initiated after July 1990 is given in Appendix C of the *Surface Water Improvement and Management (SWIM) Plan Update for the Indian River Lagoon* (Steward et al. 1993). Appendix F of that document also includes detailed summaries of 22 ongoing projects in the five SWIM programs for the Indian River Lagoon:

- Water and Sediment Quality (12 Projects)
  - Water quality monitoring network: point and nonpoint pollution source assessment
  - Toxic substances monitoring network
  - Muck sediment identification and control
  - Nutrient loadings assessment
  - Turkey Creek watershed management plan
  - Sebastian River watershed management plan
  - Storm water management
  - Hydrologic and hydrodynamic monitoring/modeling
  - Land cover mapping for nonpoint source identification
  - Pathogen sources ID and control
  - St. Lucie County management project
  - Martin County management project

- Habitat Preservation and Restoration (3)
  - Seagrass preservation/restoration
  - Wetlands restoration/preservation
  - Land acquisition

- Regulation and Enforcement (3)
  - Inventory of gravity drained agricultural runoff and assessment of water quality impacts
  - Storm water research and rule development: design guidelines and criteria for retention with filtration systems

Increased investigation and enforcement of on-site sewage disposal systems, point source discharges, and storm water treatment systems

- Public Awareness Program (1)
  Public awareness program

- Administration, Planning, and Coordination (3)
  Indian River Lagoon data bases
  Indian River Lagoon scientific information system
  Plan development

Project IR-4-501-S is developing a computerized data base repository for hydrologic, hydrodynamic, water quality, sediment and biological data for the Indian River Lagoon. The SWIM program will rely heavily on the Data and Information Management Strategy (D.I.M.S.) presently in development under the direction of IRLNEP and a D.I.M.S. committee, which includes representatives from the St. John's River and South Florida Water Management Districts. D.I.M.S. will coordinate the retrieval and exchange of water quality data primarily, and then other types of data (including GIS) as D.I.M.S. matures. Available datasets have been enumerated for the St. Lucie Estuary by Mahadevan and Lowrey (1993).

IRLNEP Project Summaries for Fiscal Years 1991, 1992, 1993, and 1994, as provided by NEP, follow the Bibliography section of this report.

ACKNOWLEDGMENTS

In response to an invitation from the Science SubGroup of the South Florida Ecosystem Restoration Inter-agency Working Group, seventeen scientists from organizations with interests in the upper east coast planning area gathered at the U.S. Fish and Wildlife Service office at Vero Beach, Florida on March 22, 1994. Those assembled presented views of research and information needs and critical issues in the region, participated in discussions, and contributed written statements to assist those responsible for the formulation of the federal Science Plan for South Florida. Gratitude is extended to these individuals and their organizations for their contributions; they of course bear no direct responsibility for the final product, although it would be the poorer absent their counsel.

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Indian River Lagoon National Estuary Program Project Summaries for Fiscal Years 1991--1994
(The first two numerals of the project number indicate the fiscal year.)

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
91-1 DIMS	E 49,467	SJRWMD #92W105/ Cont. Shelf	04/09/92 - 01/22/93	Data & Info Mgt Strategy Report
91-2 Program Inventory/ Base Program Analysis	E 48,976	SJRWMD #92W106/ East Central Florida Regional Planning Council	01/24/92 - 09/04/92	Inventory & Analysis of Existing Gov. Regulatory & Management Programs with FOLIO Data Base Supplement
91-3 Impacts of Pruning Mangroves	E 15,000 M 30,000 (+15,000 SFWMD)	SJRWMD #93W248 FL Dept of Environ. Protection	09/93 - 03/95	A study will be performed to determine the impact of pruning mangroves on productivity and habitat value. (See FY93 WP for complete project update)
91-4 SAVI I	E 48,058	SJRWMD #92W337	10/91 - 10/92	Development of the SAV Initiative and the focus of SAV as the "theme" for the IRLNEP, SAV Mapping of entire lagoon, SAV Workshop
91-5 Water Quality Monitor				This project was orig. in the FY91 WP as match, was removed when the Asst. Agree. was amended.
91-6 Toxics Monitoring I	M 102,500	SJRWMD #90B180 FL Tech	10/91 - 06/93	A draft report: Toxic Substances Survey for the IRL System was submitted in Feb 93 identifying the current status of trace metal contamination in sediments, water and biota for the IRL.
91-7 Toxics Monitoring II	E 40,000	SJRWMD #90B180 Amend 2, FL Tech	10/91 - 09/93	This is the organic portion of the above contract, this report is complete and being reviewed.
91-8 Agricultural Runoff Inventory		SJRWMD #92W196 USDA - Soil Conservation Service	02/92 - 07/93	This project was originally budgeted at $45,000, SCS completed the project at no cost to the NEP. The report has been published and is undergoing review. This report includes updated maps of ag. ops. an inventory of BMPs and their effectiveness in protecting water quality.
91-9 Turkey Creek Sebastian River Hydro & Salinity	M 77,967	SJRWMD #90B207 FL Tech	10/91 - 03/94	A network to collect meteorologic and hydrologic data for the model has been established and data collection is ongoing.

Indian River Lagoon Project Summaries (continued).

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
91-10 Water Quality Circulation Model	E 36,784	SJRWMD #92W129 University of Florida	05/92 - 06/93	The report was submitted in April 93, which reviewed modeling efforts in the lagoon and compared the results of 1-D & 3-D models. The 3-D models provide much more detailed information in circulation and transportation in the lagoon.
91-11 Reconnaissance Report Update	E 23,796	SJRWMD	07/92 - 09/93	An individual was hired to review and verify lagoon data and format the data sets in the SJRWMD data base. A status and trends report has been completed and a nutrient budget is being developed.
91-12 Coordinate ELCs	E 11,836	SJRWMD #93W137 Volusia Co. DEM	02/92 - On-going	A regional Environmental Resources Directory has been distributed and the Electronic Bulletin Board "Lagoon Net" is operating and continues to be refined.
93-13 Citizens Monitoring	E 10,000	SJRWMD #92W246 Marine Resources Council	10/92 - 10/93	The training guide has been completed and the additional monitoring sites being funded by NEP are collecting data.
91-14 Teachers Environmental Education	E 21,132	SJRWMD #92W280 University of Central Florida	07/92 - 10/92	Two 10 day summer institutes were held for environmental educators involving "hands-on" instruction. This project was chosen by Congressman Jim Bacchus as one of four outstanding innovative educational projects in the region.
91-15 Neighborhood Action Plans	E 20,000	Print Media Associates Data Management	02/92 - 02/94	This project will develop the "Owners Guide to the Indian River Lagoon." The text and art work is complete, printing will be completed in February 1994.
91-16 General Public Outreach	E 20,012	SJRWMD	10/91 - 09/92	This project produced two posters of the lagoon system, a synchronized sound/slide shown, several newsletters about program activities, an exhibit display, two stormdrain stenciling events.
91-17 Watershed Action Committees	E 25,694 M 8,563	SJRWMD# 92W216, 92W217, 92W218, 92W219, 92W221, SFWMD# SJ93W174 & 79	10/91 - 05/93	This project included funding for six separate WACs with seven demonstration projects.

Indian River Lagoon Project Summaries (continued).

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
92-1/CR-1P-CR-6P Circulation Report	E 275,000	SJRWMD #93W111 Woodward-Clyde Consultants	02/93 - 03-94	Data assembly & review, physical features, biological resources, status & trends, and priority problems are approximately 90% complete; draft copies of the historical imagery, uses of the lagoon, and governmental programs have been provided to IRLNEP for review.
92-2P SAV Inventory & Analysis	E 80,000	SJRWMD#93W216 FL Tech SJRWMD#93W203 Brevard Co SJRWMD #93W175 IRiver Co SJRWMD #93W199 HBOI	03/93 - 05/94 01/94 - 01/95 02/94 - 02/95 08/93 - 06/95	PAR monitoring data from Brevard & Indian River Counties, intensive PAR monitoring data from HBOI, reprinting of the SAV workshop proceedings, and review & analysis of historic benthos samples are the products to be delivered under this project.
92-3P Data & Info. Mgt. System Implementation	E 40,000	SJRWMD SFWMD	10/92 - 10/93	This project is funding continuation of a data manager to verify and format data sets for the lagoon. Data management review & status completed. GIS workshop held.
92-4P Fed. Asst. Programs Invent. & Consist. Analy.	E 10,000	SJRWMD #93W182 ECFRPC	04/93 - 08/93	This project produced a report which identifies the goals and purposes of federal assistance programs in the IRL.
92-5P Lagoon Partners Fund	E 40,000	SJRWMD #93W175-176-181-183-186-208-284-285	10/92 - On-going	This project provides "mini-grants" for demonstrations projects in the lagoon. Eight grants were issued under the FY 1992 LPF.
92-6P Public Awareness Campaign	E 25,000 M 75,000	SJRWMD #93W139 WMFE PBS Station	01/93 - 02/94	The speakers bureau video and the 1/2 hour broadcast quality video are complete, four 30-second PSAs will be completed by Feb. 1994.
92-7P General Public Outreach	E 7,200	SJRWMD	10/92 - 09/93	This project provided funding for promotional posters, facts sheets, etc.
92-8P Watershed Action Committee	E 28,000 M 6,666	SJRWMD SFWMD	08/93 - 10/94	This project will provide funding for demonstration projects through the eight WACs along the IRL.

Indian River Lagoon Project Summaries (continued).

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
92-9M Turkey Creek/Sebastian River Hydro	M 100,000	SJRWMD #90B207 FL Tech	10/92 - 03/94	This is a continuation of Project 91-9 to develop a 3-D model of the IRL in the vicinity of Turkey Creek.
92-10M Photointerp. & Digitization of SAV Coverage	M 20,000	SJRWMD #92W102 Natural Systems Analysis	10/92 - 01/93	Review of aerial photo of SAV coverage from several years to help discern spatial and temporal trends.
92-11 Determination of an Ecologically Desirable Salinity Regime	M 50,000	SJRWMD #92W177 Mote Marine Laboratory	10/92 - 12/92	Calculation of the most desirable salinity regime in the Sebastian River to assist in the timed release of freshwater discharges.
92-12M Assessment of Agricultural Drainage	M 15,000	SJRWMD #92W130	11/92 - 03/93	An inventory and analysis of ag. activity lagoon-wide to determine the annual and seasonal and suspended matter loadings to the primary canals in three of the lagoon's water control districts.
93-1/SAV-1P SAV Mapping	E 40,000 M 9,000	SJRWMD	10/93-12/94	SAV Mapping throughout the lagoon
93-1/SAV-2P Lagoon Bathymetry	E 50,000	SJRWMD	10/93 - 12/95	The scope of work is complete for the development of a bathymetric map of the IRL. An RFP will be issued in February 1994.
93-1/SAVA-3P Light Availability Model	E 30,000	SJRWMD	10/93 - 12/95	Mathematical models will be developed to determine target levels for total suspended solids, color, and chlorophyll to control pollutants affecting light penetration.
93-1/SAV-4P Lagoon Segmentation	E 20,000 M 42,733	SJRWMD	10/93 - 12/94	Segmentation of the IRL for analysis and management purposes.
93-1/SAV-5P Lagoon Monitoring	E 30,000 M 35,000	SJRWMD	Ongoing	Water quality and PAR data from throughout the lagoon for use in light availability modeling, etc.
93-1/SAV-6P Digitization of 1949 USGS Quads	E 31,700	SJRWMD	10/93 - 06/94	The scope of work is being developed for the digitization of 1949 USGS 7.5' quadrangles of the IRL region and an estimate of pollutant loadings by basin during that era.

Indian River Lagoon Project Summaries (continued).

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
93-2/PIE-1P General Public Outreach	E 60,000 M 3,000	SJRWMD Brevard Co.	10/93 - 12/94	Workshops, displays, education materials, etc.
93-2/PIE-2P Lagoon Partners Fund	E 50,000	SJRWMD #94W105-106-107-121-122-123-138-155-156-157-158	Ongoing	Continuation of 1992 Lagoon Partners Fund grant program. Eleven projects have been approved so far this year totalling over $40,000.
93-2/PIE-3P Citizens Water Quality Monitor	E 80,000	SJRWMD	Ongoing	Support for the continuation of citizens water quality monitoring programs. The Volusia Co. Dept. of Env. Mgmt. is completing a combined scope for this project. Contracts will be initiated in March 1994.
93-2/PIE-4P WACs	E 40,000 M 30,000	SJRWMD	Ongoing	Support for demonstration projects for the eight WACs within the lagoon. The NEP and SWIM are working in coordination to foster these projects.
93-3/CCMP-1	E 145,000	SJRWMD #94W118	04/94 - 11/95	The scope of work has been approved by the Mgmt Conf & an RFP has been issued with a proposal opening of March 4, 1994.
93-3/CCMP-2 Printing & Pub. of CCMP Material	M 150,000	SFWMD	10/93 - 12/95	Printing of documents to be included in the CCMP.
93-3/CCMP-3 Conferences & CCMP Hearings	E 25,000 M 20,000	SJRWMD #94W103 SFWMD	10/93 - 12/94	Three sub-regional assemblies have been held in the north, central & southern portions of the lagoon and action plans are being developed to take to the regional action agenda assembly.
93-4/DI-1 Program Inventory & Analysis Update & Maintenance	E 10,000	SJRWMD	Ongoing	Update of Government Programs Inventory and Analysis
93-4/DI-2 DIMS Implementation	E 10,000 M 42,500	SJRWMD SFWMD	Ongoing	Funding to support a permanent data manager and to implement the recommendations of the DIMS report.

Indian River Lagoon Project Summaries (continued).

PROJECT	FUNDING E-EPA M-MATCH	SPONSOR/CONTRACTOR	PROJECT DATES	PRODUCT/DELIVERABLE(S)
94-1/SAV-1 Bathymetry	E 80,000 M 21,700	SJRWMD	10/94 -	Final phase of research initiated in 1992 to develop a fine scale bathymetric survey of the IRL.
94-1/SAV-2 Light Modeling	E 30,000 M 50,000	SJRWMD	10/94 -	Second phase of research project initiated in the 1993 workplan to develop a model which identifies parameters affecting light penetration in the IRL.
94-1/SAV-3 Monitoring	E 25,000 M 26,499	SJRWMD Counties	10/94 -	Continued support for the lagoon-wide water quality and PAR monitoring network.
94-2/PIE-1 Lagoon Partners Fund	E 50,000	SJRWMD	Ongoing	Continuation of the successful "mini-grant demonstration/education program initiated in the 1992 Workplan
94-2/PIE-1 Citizens Monitoring	E 50,000 M 62,517	SJRWMD SFWMD FDKP	Ongoing	Continued funding to support the network of citizens water quality monitoring.
94-2/PIE-3 Public Outreach	E 50,000 M 4,951	SJRWMD SFWMD	10/94 -	Support for activities that promote education and awareness of the objectives of the NEP and CCMP development.
94-2/PIE-4 WACs	E 40,000 M117,666	SJRWMD Counties	10/94 -	Support for the WACs demonstration projects.
94-3/CCMP-1 CCMP Implementation	E 50,000	SJRWMD	Ongoing	Continuation of the development of the implementation plan for the CCMP.
94-3/CCMP-2 Finance Report	E 50,000	SJRWMD	Ongoing	Continuation of the development of the finance plan which identifies the costs and funding sources to implement the CCMP.
94-3/CCMP-3 Printing/Publishing	E 60,000 M 30,000	SFWMD	10/94 -	Printing of documents to be included in the CCMP.
94-3/CCMP-4 Conferences/Meetings	E 35,000 M 20,000	SJRWMD SFWMD	10/94 -	Workshops, public hearings, etc. to disseminate information on the CCMP and to receive public comments

APPENDIX

Papers Presented at March 22, 1994 Research Planning Workshop
Vero Beach, Florida

In response to an invitation from the Science SubGroup of the South Florida Restoration Interagency Working Group, seventeen scientists from a variety of organizations with interests in the Upper East Coast planning area gathered at the U.S. Fish and Wildlife Service's conference facility at Vero Beach on March 22, 1994. The assembled group made formal and informal presentations of their views on research and information needs and critical issues in the region, participated in discussions, and several contributed written statements to assist those responsible for the formulation of the federal Science Plan for South Florida. Gratitude is extended to these individuals and their organizations for their contributions; they of course bear no direct responsibility for the final product, although deserving of credit for their contribution to such good qualities as it may possess. The written contributions submitted at the workshop are herein appended, following a complete list of those in attendance.

Research Needs Workshop, Vero Beach, Florida, March 22, 1994

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RESEARCH NEEDS

SUB-REGION 2. LAKE OKEECHOBEE AND THE EAST/WEST WATERWAYS AND SUB-REGION 3. NORTH PALM BEACH, MARTIN, AND SOUTH ST. LUCIE COUNTIES

James R. David
St. Lucie Co. Mosquito Control District
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I. A PROPOSED SOLUTION TO THE FRESHWATER IMPACTS TO THE INDIAN RIVER LAGOON/SAINT LUCIE RIVER ESTUARY IS TO CONSTRUCT A REGIONAL ATTENUATION FACILITY (RAF), OR RESERVOIR, FOR THE C23, C24 AND C25 BASINS

RESEARCH NEEDS

A. Develop hydrological models of the three basins which should include drainage needs, water supply needs, storage design requirements, Floridan aquifer water quality impacts and Inlet(s) flushing impacts

B. Examine the environmental impacts of construction at the location of potential RAF sites

C. Evaluate the ecological impacts of pre- and post-RAF construction vis-a-vis: fish deformities; oyster indicator envelope (where relevant); ooze and muck removal/transport; Photosynthetically Active Radiation (PAR)/light transmissivity and bathymetry as they are related to potential seagrass distribution and health; trace/heavy metal/toxics concentrations

II. PROPOSED SOLUTIONS TO REDUCE GROUND-WATER LOSS, AND REDUCE DISCHARGES OF MODERATE VOLUMES OF REDUCED WATER QUALITY, FROM EIGHT (8) SECONDARY NSLWMD CANALS USED FOR AGRICULTURAL AND RESIDENTIAL DRAINAGE INTO THE NORTH FORK OF THE SAINT LUCIE RIVER, INVOLVE THE CONSTRUCTION OF WEIRS AND SMALL ATTENUATION FACILITIES (SAF) TO INCREASE THE LEVEL OF GROUNDWATER STORAGE TO REDUCE IMPACTS UPON THE FLORIDAN AQUIFER, AND TO INCREASE WATER RESIDENCE-TIME IN ORDER TO IMPROVE WATER QUALITY

RESEARCH NEEDS

A. Model freshwater basins of the eight canals for weir design needs for groundwater recharge, drainage and location of Small Attenuation Facilities (SAF) which could add storage in the basins

B. Examine the environmental impacts of weir/SAF construction at potential site locations for the eight canals

C. Model the downstream impacts of freshwater, organic and toxics loads, and model load reduction provided by the weir/SAF system

III. A PROPOSED SOLUTION TO FRESHWATER IMPACTS UPON THE INDIAN RIVER/SAINT LUCIE RIVER IS TO OPTIMIZE OCEANIC EXCHANGE THROUGH THE INLETS (IN ORDER TO REDUCE THE ANTICIPATED COSTS OF ESTUARINE RESTORATION AND PRODUCE A MORE RAPID RECOVERY OF THE ESTUARY)

RESEARCH NEEDS

A. Perform bathymetric studies of the Inlets and estuary to establish potential seagrass restoration sites

B. Develop hydrological models of Inlet(s) exchange as it is related to freshwater discharge from canals, PAR/light transmissivity and seagrass abundance, restoration and health within the estuary

C. Examine environmental impacts related to reduced sand transport by Inlets with "optimized" (vis-a-vis freshwater impacts) oceanic exchange, as well as, environmental impact studies of Inlet design improvements which result in reduced sand transport (and less beach renourishment)

IV. PROPOSED SOLUTIONS TO COASTAL IMPOUNDED WETLAND ISOLATION INCLUDE RESTORATION OF TIDAL EXCHANGE, SEASONAL MANAGEMENT AND ACQUISITION

RESEARCH NEEDS

A. Perform studies on recruitment and habitat needs of marine fishes with wetland nursery requirements
B. Perform studies on wading bird post-breeding requirements and the impacts of wetland management on juvenile success
C. Perform studies on benthic organism habitat requirements, toxic substance uptake (and amplification) and reproductive success in coastal wetlands
D. Perform studies on managed wetland enhancement of coastal and estuarine fisheries stock
E. Perform studies on recruitment of juvenile fishes to estuaries and evaluation of such samplings as assessments of fishery populations

V. IT HAS BEEN PROPOSED THAT THE BIODIVERSITY OF THE INDIAN RIVER LAGOON SYSTEM BE PROTECTED BECAUSE IT BEEN REPORTED THAT THE GREATEST LEVEL OF BIODIVERSITY FOR ANY ESTUARY IN THE CONTINENTAL UNITED STATES OCCURS IN THE INDIAN RIVER LAGOON

RESEARCH NEEDS

A. Examine and develop comparative species records and species richness/diversity maps for locations within the Indian River Lagoon/Saint Lucie River system which are impacted and non-impacted by freshwater discharges
B. Establish a monitoring program which evaluates the effectiveness of restoration efforts upon biodiversity, for coastal wetlands and estuarine waters at those specific impacted locations
C. Provide suggestions for, and studies which contribute to, remediation plans for those areas deemed to have impacts upon biodiversity by freshwater discharges
D. Evaluate the success of Pollution Load Reduction Goals vis-a-vis biodiversity

March 18, 1994

Lawrence A. Burns, Ph.D.
Research Ecologist
U.S. Environmental Protection Agency
Environmental Research Laboratory
960 College State Road
Athens, Georgia 30605-2720

Re: Central and Southern Florida Flood Control Project/ Congressionally-Authorized Restudy by the U.S. Army Corps of Engineers

Dear Dr. Burns:

This is in response to your letter of March 2, 1994, requesting suggestions on research needs and issues analysis for the geographic area embraced by the project referenced above. This material will be presented to you in this hard copy format and on an IBM-compatible disk, WordPerfect 5 text.

As the Chief Engineer of the North St. Lucie River Water Control District (NSLRWCD) in St. Lucie County, Florida, I offer the following research needs and issues analysis, as we see them in our geographic area of interest and knowledge.

1. Discharge from Canals C-23, C-24, C-25 and C-44.

(a) It has been suggested by others that releases from these canal systems should be modified to decrease discharge during the wet season, and increase discharge during the dry season. However, these modifications, if any, must be made only after considering a balancing of needs for public water supply, agricultural water supply, drainage, and socio-economic benefits. A water budget must be prepared that realistically reflects these needs and their global impact on the environment and the economy.

Optimum discharges can be attained in part with the use of a regional attenuation facility (RAF) located within the area of influence of canals C-23, C-24 and C-25. This RAF could be used to store water in times of plenty, thereby reducing flows to the Indian River Lagoon during the wet season. During the dry season, it could be used to provide fresh water flows to the lagoon, as needed.

Accurate data, realistic research, and hydraulic and hydrologic modeling must be performed to determine these optimum flows.

(b) The 34-year operating history of C-23, C-24 and C-25 reveals that none is performing as originally designed in the 1950s. However, the original design information is still being used to estimate the reaction of those systems to rainfall events.

Therefore, actual flood profiles must be prepared for these three canals that accurately reflect their response to inflow and operating conditions. It is imperative that this data be prepared for the restudy to have any credibility.

2. **Weir Structures in Secondary Canal Systems.**

Weir structures in secondary canal systems discharging to the North Fork of the St. Lucie River, including those of the NSLRWCD, could assist in accomplishing more flexibility in the discharge of water from those systems.

Hydrologic studies to determine fresh water needs, groundwater recharge potential, and maintenance of historic drainage is required to determine where these structures should be installed.

Also, environmental impacts of the selected locations for these smaller attenuation facilities should be evaluated.

3. **Modification of Fixed Crest Spillways.**

Fixed crest spillways in C-23 (structure S-48) and in C-25 (structure S-50) could be modified to offer more flexibility in water storage and discharge capability.

Therefore, this option should be investigated and evaluated.

4. **Groundwater Contour Maps.**

It is important to understand the interaction between the surface water systems and the groundwater table in the areas impacted by St. Lucie County's major canal systems.

Therefore, recent and accurate groundwater table maps of the area should be prepared.

5. **Data Collection Network for St. Lucie County.**

A data collection network is needed to assess the reaction of St. Lucie County's surface water management system to rainfall, groundwater table conditions and stages. Without this basic data, it is not prudent to evaluate, or recommend modifications to, the existing systems.

Data needed includes stage and discharge for designated rainfall events, and water quality information.

These are just a few of the research needs and issues analysis that come to mind. As others may become evident at the meeting on March 22, I would like to call them to the attention of the participants.

Sincerely,

Richard B. Hellstrom, P.E.
Chief Engineer, North St. Lucie
River Water Control District

cc: Harold F. Brown

WRITTEN BRIEF

PALM BEACH COUNTY, FLORIDA ESTUARINE NATURAL RESOURCES INVENTORY AND RESOURCE ENHANCEMENT STUDY

MARCH 31, 1992

BY PALM BEACH COUNTY
DEPARTMENT OF ENVIRONMENTAL RESOURCES MANAGEMENT

The estuarine waters of Palm Beach County (PBC), Florida are contained within a shallow elongated lagoon 45 miles long with approximately 100 miles of shoreline. This study is part of an ongoing documentation of the county's estuarine natural resources. PBC Department of Environmental Resources Management (ERM) began its first inventory of intracoastal habitats in 1990 in the Lake Worth Lagoon Natural Resources Inventory and Resource Enhancement Study (Dames & Moore Inc., 1990). This second resource inventory includes the area north of Lake Worth Lagoon to Martin County, and the areas south of Lake Worth Lagoon to Broward County.

A primary objective of this study is to inventory impacted and natural areas for potential habitat restoration and enhancement. Field studies were conducted during the spring, summer, and fall of 1991 by ERM. The studies produced resource baseline information that is presented on maps. The maps include information on:

1. **Bathymetry:** The bathymetry map was created by digitizing the one-half and one meter contour lines found on the United States Geological Survey quadrangle maps. Spot depths and shoal areas throughout the study area were established by field measurements.

2. **Shoreline Characteristics:** The north and south portions of the shoreline in PBC were different in character with the south end of the county being considerably more developed. The shoreline at the north end of the survey (including canals) was 53% bulkheaded and 30% vegetated with mangroves. The shoreline at the south end of the survey was 89% bulkheaded and 7% vegetated with mangroves.

3. **Submerged Natural Resources:** The north end of the survey contained larger contiguous areas of seagrasses, principally in Jupiter Sound and the Loxahatchee River. These areas contained all of the *Syringodium filiforme* and *Thalassia testudinum* observed in this survey. In acreage, more *Halodule wrightii* was found in the north part of the survey than in the south, and more *Halophila* spp. was found in the south part of the survey. Almost all of the oyster beds were found in the Loxahatchee River. Corals and sponges were found only in the inlet areas.

4. **Manatee Habitat:** PBC estuarine waters provide year round habitat for manatees. Information gathered from over 1000 sightings of manatees was used to characterize manatee habitat within the estuarine waters of PBC. This map also includes the waters of Lake Worth Lagoon. The manatee habitat types designated are: 1) feeding areas, 2) resting/protected areas, 3) travelling areas, 4) freshwater attractant areas, and 5) warm water attractant areas. In many cases, areas were given more than one habitat type designation.

5. **Manatee Survey Location Data:** PBC, in cooperation with the Florida Department of Natural Resources (FDNR), began performing aerial censuses of manatees in PBC estuarine and marine waters twice per month in September, 1990. A total of 1128 manatees were sighted, of which 78 (9%) were determined to be calves. PBC estuarine waters were arbitrarily divided into 9 zones for analysis. The numbers of adult and juvenile manatees and their associated behavior are discussed for each of the nine zones.

6. **Marinas and Docks:** The facilities and dockage were characteristically different within the survey areas. In the northern area, 15 of the 23 facilities were commercial, in the southern area, 8 of the 43 facilities were commercial. Five boat ramps are in the northern area, and two boat ramps are in the southern area of the survey.

7. **Habitat Restoration and Enhancement Project Areas:** The ultimate goal resulting in the recommendations and proposed projects in the previous (Dames & Moore Inc., 1990) and current natural resources inventory is an increase in the habitat value and an increase in PBC's natural resources. A total of 64 potential project sites were identified, with 35 in the north and 29 in the south. An analysis of the ownership of the properties in the 64 potential project locations included 43 projects with publicly owned properties, and 32 projects with privately owned properties. PBC owned 10 properties, 8 in the north and 2 in the south. The County owns a total of 3.1 miles of shoreline considered in this survey for enhancement purposes, 2.9 miles in the north and 0.2 miles in the south.

RESEARCH NEED FOR HYDROLOGY MODELING FOR THE HABITAT ENHANCEMENT AND MANAGEMENT OF LAKE WORTH LAGOON

The West Palm Beach Canal (C-51) has had a profound impact on the Lake Worth Lagoon estuary as a major contributor of nutrients and sediments. Surveys have documented the accumulation of organically enriched silts in the vicinity of the C-51 Canal discharge.

The South Florida Water Management District's (SFWMD) redesign of the C-51 water basin, and the quality and quantity of discharges into the Lake Worth Lagoon are important in determining the long term viability of the estuary. How will this change affect the water quality, salinity, sedimentation, turbidity, and circulation of the Lake Worth estuary? To make competent management decisions, and enhance the Lake Worth Lagoon we need the expertise and resources of the SFWMD to design a hydrologic model of the lagoon for the specific purpose of enhancing and managing the estuary.

Science SubGroup Research Needs Assessment
Vero Beach Workshop Presentation
by Donna M. Smith
USDA Soil Conservation Service
21 March 1994

I am a hydrologist responsible for coordinating SCS's activities in support of the Indian River Lagoon National Estuary Program. In the way of an introduction, the following is offered and thought to be of significance to the proposed research topics. Among the activities that SCS initiated are an agricultural inventory, water quality research in citrus, and the establishment of two Mobile Irrigation Labs (MIL's) in the IRL basin.

In the C-25 basin there are 35,605 acres of citrus and 8,917 acres of range and pasture. The inventory showed that there are 38,793 acres being irrigated, with 32,657 acres of low volume, spray jet or drip (84% of the total irrigated) and 6,136 acres of crown flood.

Similarly, the C-24 basin has 20,870 acres of citrus, 120 acres of cropland (vegetables) and 43,556 acres of range and pasture. There are 20,870 acres being irrigated with 15,536 sprayjet (74%) and 5,334 flood. The C-23 basin has 22,596 acres of citrus and 13,602 acres of range and pasture. There are 22,596 acres irrigated with 17,015 sprayjet (75%) and 5,581 flood.

In FY 1993 and the first half of FY 1994 in the North St. Lucie River Water Control District we have evaluated [with the MIL's] 30 irrigation systems on 432 acres (all sprayjet) and made recommendations for increased emission uniformity for a potential water saving of 10,952.12 acre inches of water per year.

In addition to these project activities, normal field office operations include performing irrigation evaluations and water management plans similar to those being done by the MIL's. Another program is the water table observation well installation program, where water table observation wells are used to schedule irrigation. In Indian River County alone, 400 wells have been installed serving 15,000 acres and 72 cooperators.

For a discussion of research needs, under the headings:

<u>Ecological Restoration Objective:</u> Remove muck from benthic areas of the IRL to reestablish seagrass beds and estuarine productivity.

I thought that the Taylor study[1] had put this issue to rest, showing it to be cost-prohibitive, but regardless, this issue only makes me think of the source of the sediment. The source needs to be identified and stopped. Research data collected by SCS and others have shown that very little sediment is leaving mature citrus groves. If you've ever been in a citrus grove you know that they are grassed over and the farm ditches have water control structures when crown flood irrigation is used. My theory is that a lot of sediment comes from unpaved roads with the majority coming from canal banks during stormwater discharge. One research need is to identify the source of this sediment and quantify the amount from each source so that BMPs can be developed.

SCS designed and cost shared 2 radial gate structures on Ten Mile Canal in the 1950's under the authority of PL-566. These gates open from the bottom allowing suspended matter to continue downstream. These gates need to be retrofitted with gates with a split gate design. The cost of this project would be $123,000 for the smaller (Fittings Structure with three 4x7 foot gates and $190,000 for the larger (Gordy Road Structure with

[1] Schropp, S.J., W.F. McFetridge, and R.B. Taylor. 1994. St. Lucie Estuary Muck Removal Demonstration Project: Final Report. Prepared for South Florida Water Management District, Contract C-3269. Taylor Engineering, Inc., Jacksonville, Florida. 116 pp. + Appendices.

four 18x6 foot gates). There is also a need for a sediment control structure on Ten Mile between these two structures. Acquiring the funding for these retrofits would be a full time job for someone. I recently wrote a grant proposal for a Coastal Zone grant funded by NOAA and they didn't care for the project. We're waiting for the official turn down, but one of their big concerns was that we did not quantify the amount of reduction of sediments. We had given them the amount of deposition from the Taylor report [op. cit.] as 0.20 to 0.39 inches per year with an estimated 13,500 tons of sediment per year to the St. Lucie Estuary. This is another research need. Someone might also research where the money for the retrofit is coming from.

Hydrological Objective: Maximum freshwater discharges into the IRL through C-23, C-24, C-25 and C-44 should not exceed 2500 cfs.

I'm assuming that there was some research done to tie this into some ecological need[2]. How are we going to accomplish this? The agricultural community favors a regional approach rather than a grove by grove regulatory approach to reduce fresh water discharge. Most everyone can see that Regional Attenuation Facilities (RAF's) are the answer. Site location, land acquisition, permitting and site development will be time-consuming and expensive, but will be necessary to achieve 2500 cfs or anything close to it.

[2] [Study reported by D. Haunert at Vero Beach workshop, March 22, 1994.]

Establishing Long-term Net Transport Patterns in Estuarine and Continental Shelf Waters

Ned P. Smith
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INTRODUCTION

An understanding of the movement of water in estuaries and over adjacent continental shelves serves as a least common denominator for a wide variety of ecological issues. By itself, volume transport defines circulation patterns associated with the movement of water through an estuary, the exchange of estuarine and shelf water though any connecting inlets, and the transport of water along and across the continental shelf. Studies of volume transport are rarely conducted alone, however. For most practical purposes the usefulness of transport studies rises dramatically when simultaneous measurements are made of what is contained within the water. When combined with any measure of dissolved or suspended material in the water, the result is directly applicable to pollutant transport, nutrient transport, larval transport and suspended sediment transport. When this broader approach is taken, transport studies are of fundamental importance whenever one wants to track the movement of dissolved or suspended material.

SCOPE

Within the geographical context of the coastal zone, one is usually concerned specifically with (a) estuarine transport, (b) continental shelf transport and (c) transport through the connecting inlets. Estuarine transport involves the mixing of fresh and salt water within the estuary itself. Continental shelf transport studies are divided generally into investigations of along-shelf and across-shelf transport. Across-shelf transport in particular is of central importance to the recruitment of larvae in those instances when adults spawn offshore and estuaries serve as juvenile nursery areas. Transport studies in inlets usually deal with the amount of water exchanged on a given tidal cycle, and on the long-term flood-dominant or ebb-dominant nature of the inlet.

In terms of the transport processes involved in coastal zone studies, the scope of a study must be broad enough to include (a) the ebb and flood of the tide, (b) the movement of fresh water through an estuary under both wet season and dry season conditions, (c) density-driven currents resulting from the juxtaposition of fresh water and salt water, and (d) the wind-driven movement of water arising with weather systems moving over the coastal zone or the seasonal shift in wind patterns.

In another sense, time scales of interest range from several hours (e.g., the ebb and flood of the tide) to several months (e.g., the changing patterns that arise in response to seasonal variations in wind and/or rainfall). The instantaneous ebb and flood of the tide may be the most apparent transport process at a given time and place, but the net movement over repeated tidal cycles may be relatively small. Longer time scales must be considered to determine the magnitudes and relative importance of all relevant processes.

RESEARCH NEEDS

(a) Estuarine transport

Transport processes in Indian River lagoon are undoubtedly better understood than are transport processes in shelf waters and in the connecting inlets. Nevertheless, the majority of measurements have been made in the relatively deep and protected waters of the Atlantic Intracoastal Waterway (AIW). While this has undoubtedly resulted in a higher data return, it has left open to question the role played by the relatively shallow waters on either

side of the AIW in lagoonal transport patterns. Only recently have measurements been made to provide a better picture of the lateral structure of the flow patterns. To date, the variability has been documented, but no coherent picture has emerged. It appears that tidal ebbs and floods occur nearly simultaneously through a given cross-section. Similarly, nontidal flow over time scales on the order of days to perhaps weeks occur simultaneously within and on either side of the AIW. Over the longest time scales, however, the flow in the AIW is not consistently related to the flow in the shallow waters. An understanding of long-term net transport patterns can be applied to the movement of fresh water through the lagoon, as well as to the transport of larvae from lagoonal or shelf spawning sites. Such an understanding will require more simultaneous in situ data combined with weather measurements, and perhaps supported by modeling studies if the cause-and-effect processes are not a direct response to local forcing.

(b) Continental shelf transport

As noted above, the two central issues within the context of continental shelf transport involve the movement of water along and across the shelf. Along-shelf transport is usually dominant, but the across-shelf deflection of a predominantly along-shelf flow is of importance in recruitment studies (where landward transport is needed to carry larvae toward inlets) and in pollution studies (where seaward transport is needed to carry water of low quality away from the coast and to open ocean waters where it can be diluted).

Along the Atlantic coast of Florida, the along-shelf transport over the outer shelf is dominated by the south-to-north flow associated with the Florida Current. The along-shelf flow over the middle and inner shelf is less well understood, but it appears that the long-term net flow is determined by wind conditions. South-to-north flow has been reported in spring, summer and early fall months; north-to-south flow has been recorded from late fall to early spring. Only one study has followed along-shelf transport over a full one-year cycle. Additional work is needed to determine interannual variability, or simply to document the similarity of flow patterns within a given season.

The across-shelf component of the flow has received considerably less attention. Several studies between Jupiter Inlet and Cape Canaveral have documented midsummer upwelling, but this is an indirect measure of across-shelf transport. The one-year study noted in the preceding paragraph revealed a near-bottom landward deflection of the northward flow in summer months, and a similar seaward deflection in winter months. Several questions remain, however. It is not clear if this is a result of the variable width of the shelf in the study area, or a result of an imbalance of forces in near-bottom layers. Also, it is not clear if the entire water column moves landward or seaward at a given time of year, or if the landward deflection in one part of the water column is compensated locally in another part of the water column at the same time. The vertical structure of the across-shelf flow is important when larvae migrate vertically over the course of a day and occupy both near-surface and near-bottom layers in the course of a migration cycle.

(c) Inlet transport

Least understood of all is the transport through the three inlets that serve Indian River lagoon. While the total tidal transport can be determined from an analysis of water level records obtained throughout the lagoon, it is not clear what fraction of the total is contributed by the individual inlets. Nor is it clear how much additional, nontidal transport is moving through the inlets. The long-period rise and fall of water level within the lagoon can be a response to either fresh water (some combination of rainfall and freshwater runoff moving into and through the lagoon from drainage canals) or salt water (nontidal exchanges through the inlets). The effect will be quite different, according to the source. Recent studies have suggested that the three inlets of Indian River lagoon are dissimilar in terms of their ebb-dominant or flood-dominant condition. Fort Pierce Inlet appears to be ebb-dominant throughout the year; St. Lucie Inlet is ebb-dominant at times, while at other times there appears to be little net nontidal flow. Sebastian Inlet appears to undergo a transformation from ebb-dominant to flood-dominant in response to seasonal variations in rainfall, wind direction and coastal sea level. Studies are needed to confirm these preliminary findings, as well as to investigate relationships between long-term net inflow or outflow and spawning seasons of species that use the lagoon for a part of their life cycle.

APPROACH

As noted above, the approach taken to investigate physical processes in shelf and estuarine waters should combine direct field measurements with computer modeling. In situ measurements are needed to first initialize, then verify model simulations. Also, if a relatively small study area has been identified, direct measurements may be all that are needed to answer the questions being posed. On the other hand, many questions involve spatial scales large enough to make direct observations prohibitively expensive. In such cases, computer models provide a more economical alternative. Also, once cause-and-effect relationships have been established, models provide an opportunity to explore a wider range of environmental conditions than might have existed while the field study was in progress.

SUMMARY

Regardless of the modeling or observational nature of the study, many questions will require an understanding of long-term flow patterns as a first step. Measurements of nutrients, larvae, suspended sediments, etc., can then be added to focus on the specific transport processes under consideration. In terms of volume transport, several studies are recommended to establish long-term net circulation patterns:

(1) an observational study conducted in shelf waters to determine across-shelf flow over the middle and inner shelf, and at both near-surface and near-bottom levels;

(2) a combination of observational and modeling studies conducted in lagoonal waters to compare and contrast transport within and on either side of the Intracoastal Waterway; and

(3) a modeling study designed to quantify the seasonal variability of long-term net transport through each of Indian River lagoon's three inlets.

REVIEW OF CENTRAL AND SOUTH FLORIDA FLOOD CONTROL PROJECT

UPPER EAST COAST PLANNING AREA

THE AGRICULTURAL PERSPECTIVE

by

Peter D. Spyke
President, Arapaho Citrus Management, Inc.

March 22, 1994
Vero Beach, Florida

INTRODUCTION:

I appreciate the opportunity of providing input on this important topic, and for the chance to be involved at this level of planning. This is a critically important step in the water management effort in this part of the state, and I commend the agencies involved for their foresight and responsible approach to changing perspectives and demands on the system.

Arapaho Citrus Management, Inc., is involved in the management and operation of businesses which produce citrus, sod, cattle, vegetables, and timber in Martin, St. Lucie, and Indian River Counties. Clients and members of our company also live and raise families in the urban areas of all of these counties. Therefore, as a group, we have a fairly complete perspective on the overall effects of the water and land management policies and regulations in this area. We actively participate on many of the boards and committees, including the Indian River Citrus League Land and Water Management Committee, the Treasure Coast Regional Planning Council, the Florida Cooperative Extension Service Advisory Committees, and the Indian River Soil and Water Conservation District, which deal with these issues and have been a part of the planning process for many years.

COMMENTS ON EXISTING PROJECT:

My personal perspective is perhaps unique. I was born in Broward General Hospital in Ft. Lauderdale in the summer of 1951. Four years before that, in the spring of 1947, my grandfather had purchased a small citrus grove with one-year-old trees, located on the south bank of the South New River Canal in Davie, Florida. That fall, the 1947 hurricane hit. An aluminum shed is still standing on that property which shows the water mark from the ensuing flood. The moderately acid water actually etched the aluminum, and one can plainly see the tiny increments of water level change as the water drained down from the Kissimmee, Lake Okeechobee, and the Everglades across the southeast Florida. Conservatively, at its highest the water was 5 feet deep in the grove, and it must have remained at a flood stage for weeks.

That year, my grandfather and father replanted the grove, and as a result of that and other storms, the Hoover administration authorized the Central and South Florida Flood Control Project. Forty-seven years later, there are hundreds of thousands of acres of agriculture and millions of people living on land that was not useable for any human-related purpose at that time. Therefore, it is clear to me that the Project was a tremendous success, and the chances are that the very people who are engaging in the discussion about the future would not even be here were it not for the assurances provided by the water control system developed as a result of the Project.

The Project, in my opinion, was inherently "good." Therefore, the exercise at hand is <u>not</u> one of fixing a "bad" thing, but how to make a "good" thing <u>better</u>! Part of this philosophy involves the realization that the <u>only</u>

way to restore the system to its natural state would be for everyone to leave, take all of their belongings with them, and undo all of the changes they have made. Short of that, the ultimate solution will be a compromise which cannot make anything the same as what it was, but can be a sustainable situation which integrates the quality of human life with that of the natural environment.

PROJECT MODIFICATIONS:

Any modification will be a tradeoff between the human side and the environment. Nothing we do will result in a completely positive change for both sides of the issue. No improvement in the environment and natural resources can occur without human effort, financial resources, and the loss of future options. Likewise, no change from the March 22, 1994, living conditions, population density, and land use can occur without some impact on the environment and natural resources.

The challenge is to define the target balance between the human issues and the environment and natural systems. A critically integral part of this process is to educate the public that every living human being, and all of their daily living habits, are part of the forces which have changed the environment and natural systems from the pristine condition. It logically follows that the responsibility for defining the target balance, enacting the changes, and accepting the outcome must be accepted by the entire group of humans which have influence on the area. Everyone is part of the problem, and everyone has to be part of the solution.

This approach eliminates the position that certain things are anyone's sole responsibility, or that someone else should fix something. Needless to say, the agricultural industry is the primary target of this kind of thinking. The land areas under agricultural production are greater than those in the urban areas, and therefore the amount of rain that falls on agricultural land is proportionately more. This is somewhat mitigated by the fact that the off-site impact of rain that falls on a citrus grove or even a vegetable field is usually less per unit area than the runoff from urban areas. The bottom line is that improvements are necessary on all fronts to stop further departure of the natural systems from their pre-development state, and to hopefully implement some reversal of the effects of human presence.

UPPER EAST COAST AREA STORMWATER ATTENUATION:

In light of this philosophical introduction, I'll get to the salient point. Everyone knows that the primary impact of the agricultural land development in the Upper East Coast Planning Area which was enabled by the Central and South Florida Flood Control Project is over-drainage of the St. Lucie Canal and C-23, 24 and 25 Drainage Basins. To a lesser extent, inter-basin transfer through the St. Lucie Canal has had some impact. However, the fundamental problem is that stormwater moves with a directed force which exceeds the natural sheet-flow drainage pattern.

Since the fundamental problem is simple, so is the theoretical solution: slow down the rate of discharge of stormwater. There are secondary issues such as low-flows, natural areas, wildlife corridors, and so forth, but the biggie is the drainage, and related water quality effects. Attenuation of fresh water discharges is necessary to reduce the effects of the fresh water itself, the velocity-related sediments and suspended materials, and various kinds of erosion. The best method would be to create stormwater retention reservoirs to temporarily detain freshwater discharges. Economic benefit could be gained if the reservoirs could supply irrigation water during dry periods, but sufficient justification from the reduction of detrimental environmental effects of the abnormal patterns of discharge is probable. A logical location at the southwest corners of the C-23 and C-24 for at least one of these areas has been identified. More of them would be better in the long run, but this one would have a profound beneficial effect.

This stormwater attenuation facility was identified as the Number One Priority at the recent Indian River Lagoon Consensus-Building Workshop. It received support from a wide range of interests at the meeting (at which

I was the solitary representative from the agricultural industry). After the multi-disciplinary group examined almost every conceivable alternative for improving the Indian River Lagoon, this option emerged as having the most probable dramatic improvement.

Likewise, a study on agricultural discharge recently completed by the St. Johns River Water Management District in Indian River County showed that stormwater attenuation was the single most necessary change in the freshwater inflows to the Indian River. Contamination from other elements was fairly low, and the simple pattern of fresh water inflows was in and of itself the primary detrimental factor. Similar studies in the southern part of the Indian River Lagoon have shown the same thing. Therefore, the evidence pointing to this addition to the Project is overwhelming.

Likewise, a connection from the C-23 to Lake Okeechobee has been discussed at length. While it technically would allow inter-basin diversion, it could be regulated to reflect the pre-development state where some water from the C-23 did in fact drain to Lake Okeechobee under certain conditions. Without the connection, there is no option other than to run all of the water from the C-23 drainage basin out through the St. Lucie River to tide. It's entirely possible, and feasible, to combine the attenuation reservoir with this connection to the Lake.

Both of these measures are structural in nature, which has lost favor in recent years. However, it would in fact be an adjustment to the original Project design which would afford environmental improvements. It would also convert existing uplands to wetlands, eliminate the possibility of a subsequent land-use change which would require more drainage capabilities, and connect the Upper East Coast to the Everglades system. The advantage of structural projects designed to afford environmental improvements has been demonstrated with great success in the Upper St. Johns River Project, so it is not a radical approach in any sense.

IMPLEMENTATION OF THE CHANGE:

Identification of the problem, while certainly difficult and incomplete, is the easy step. The tough part is figuring out a way to change the system, and the future, in light of the many divergent interests involved with the process. In our area, we all have come to realize and accept the existing weaknesses of the system. In agriculture, we have been instrumental in organizing the studies and discussions related to the solutions. South Florida Water Management District has provided willing cooperation, generously providing staff time, District resources, and financial support for efforts to learn more about alternative solutions designed to mitigate the detrimental effects of the Flood Control Project and the resultant land uses. The Indian River Citrus League and various agricultural groups have been partners in the discussion. I believe that, at this point, there are identified alternatives, but enacting them will involve many more people than just the agricultural industry.

In many ways, it's the same situation as is the case with the Everglades Restoration Plan. The general public instinctively believes that since agriculture is occupying the land, they should be responsible for restoration efforts. This ignores certain facts: agriculture's right to be there was implied when the Flood Control Project was conceived and constructed (which was long before most of the people who are criticizing the system became Floridians); that the realization or philosophy that we should preserve the environment occurred <u>after</u> agriculture was in place (up until that time, draining the land for human use was considered to be improving the environment); that there are legally-defined private rights associated with land ownership that transcend the public interest and vice versa; and that the Flood Control Project was a <u>Public</u> work, not one of agriculture *per se*. Therefore, the public is as responsible as anyone for changes or modification in direction of the Project.

There will be significant costs involved with changing the existing plumbing system. I believe that it is the responsibility of everyone to support the effort financially and in spirit. The stormwater reservoir and connection to the Lake would be useful additions to the Project which would benefit everyone in the basins, and would improve the long-term viability of the Indian River Lagoon. From that standpoint, it would be win-win. If the general public

can be educated on the positive attributes of the changes and their responsibility to participate in the modifications, significant improvement could be made quickly. The outcome would be to permanently alleviate some of the negative environmental impact of the existing system. It is quite probable that if the changes are presented in this manner, the idea can become reality in the foreseeable future.

It must be remembered that the decisions related to environmental restoration have come about through the education and exposure of the general public, which includes agricultural operators, to the long-term effects of continued environmental degradation. The fact that anyone, farmer and homeowner alike, participated in the current state of loss of environmental function was due to a lack of knowledge of the results of our collective good intentions. Everybody has rights, opinions, responsibilities, and feelings relating to the matter, and any solution will ultimately involve us all. This philosophy should be considered in any discussion about the future of the Upper East Coast, the Everglades, or any other similar situation. Remember that the process has taken 50 years to reach the current state. The study, implementation, and financing of subsequent progress will be a similarly long-term exercise. There are no "right" answers--only those that appear to be intelligent, practical, and economically supportable. Let's work together toward that end, rather than engage in a finger-pointing exercise which is, after all, "pointless."

Again, thank you for the opportunity of participating in this meeting. I look forward to the future with the greatest of anticipation.

THE C-23 AND C-24 CANALS

A Report by Max Quackenbos
December 1993

Prepared for the
St. Lucie River Initiative, Inc.

Presented to the Science SubGroup
South Florida Ecosystem Restoration Federal Task Force

March 22, 1994
Vero Beach, Florida

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SUMMARY

The C-23 and C-24 Canals were planned, designed and built by the U.S. Army Corps of Engineers under the authority of a Congressional Act of 1948. This federal initiative - the Central and Southern Florida Flood Control Project - authorized the Corps to undertake a vast alteration of the Florida landscape. Most of the work was in the low, flat plain south of Lake Okeechobee and extending to the east coast. The primary aim was flood control with water supply a second objective. Enhancement of fish, wildlife, and other environmental resources was mentioned but in the spirit and awareness of the past was not strongly supported.

The C-23 and C-24 Canals were constructed by the Corps under the same general authority, but also with specific approval of the 83rd Congress, 1954. They were planned to improve flood control in the inland areas of Martin and St. Lucie counties, and thus promote citrus and other farming, and cattle activities.

The canals had a local sponsor - the Central and Southern Florida Flood Control District, or CSFFCD. This state authority was created in 1949 by the Florida Legislature. For the two canals the CSFFCD agreed to:

1. Contribute 20% of the cost of construction.
2. Provide the right of way.
3. Assume all responsibility including costs of operation and maintenance for the canals, which were completed in about 1960.

The South Florida Water Management District (SFWMD) was created by the Legislature in 1972 to succeed CSFFCD, with broader responsibilities for flood control, water supply, and the environment in the sixteen

southern counties of the state. Since 1972 SFWMD has owned, maintained, and operated the numerous canals and structures built by the Corps, with few exceptions.

The C-23 and C-24 canals are being recognized today as major polluters of the St. Lucie River. Together they discharge a vast amount of fresh water that upsets the salinity of the river. The discharge waters carry particles that settle as a foul ooze in the river bottom, or remain suspended as a gelatinous cloud, or a dark turbidity. These inputs intensified by those from the C-44, or St. Lucie Canal, bring devastating effects. The river has sadly declined as a haven for vegetation and animal forms. Some damage has been inflicted on the Indian River Lagoon.

Until recently the St. Lucie Canal was widely regarded as the heaviest polluter of the river - in dumping large amounts of excess fresh water from Lake Okeechobee mixed with runoffs of rural stormwater. That notion has now changed. With better management of Lake levels, the discharges have been reduced. The C-23 and C-24 are now the prime offenders - in 1992 and 1993 bringing 65% more water to the river than the St. Lucie Canal.

As the C-23 and C-24 Canals come into prominence it is evident that there is little local knowledge of their characteristics and operation. In this report we have tried to gather, analyze and condense the information scattered through several sources - mainly at South Florida Water Management District (SFWMD). So informed, local groups, and the St. Lucie River Initiative especially, will be better able to cooperate with the agencies that are now working to improve our river. They are SFWMD, the U.S. Army Corps of Engineers, and the Indian River Lagoon National Estuary Program (of the U.S. Environmental Protection Agency).

Omitting the descriptive matter that forms the bulk of this report (to be found in appendices A through F), we offer these conclusions about the C-23 and C-24:

- They operate efficiently to remove stormwater from farming areas in St. Lucie and Martin counties - a service essential to good farming.

- In the past two years, the annual amount so dumped into the St. Lucie River amounted to 350,000 acre-feet (for the Canals together).

As the canals have a small storage capacity the possible ways of reducing and diverting this water are at present:

1. On-site (farm) retention and better flow management - a partial solution with considerable reliance on 2. and/or 3.

2. Retention reservoirs - artificial and/or semi-natural

3. Transfer to Lake Okeechobee - after treatment (?). This alternative could provide extra fresh water now needed for Everglades National Park and Florida Bay.

These alternatives could include stormwater from C-44. The net total volumes involved will not be known until calculations are completed at SFWMD. These will show how much fresh water can help the North and South Forks of the St. Lucie River to maintain a beneficial salinity range, or envelope, that avoids extremes of freshness and saltiness.

ACKNOWLEDGEMENTS

The staff at SFWMD has been remarkably patient in answering questions and in providing directions to, or printouts from, good sources. Thanks for your gracious promptness.

Some of the discussion here is enriched by comments made during meetings of the Canalwater Pollution Committee of the St. Lucie River Initiative - Jim Dolan, Lee Jones, Pete Marovich, Gail Romero, Marty Sanders, Larry Schaffer.

We acknowledge, most gratefully, the secretarial help of Marianne Messersmith, Charles E. Geary, P.A.

LIST OF AVAILABLE APPENDICES

A. Design of canals and structures.

B. Operation and maintenance of canals.

C. Canal water.

D. Access to canals.

E. References.

F. Tables of information from SFWMD.

SUBREGION 4:

EVERGLADES AGRICULTURAL AREA

INTRODUCTION

The purpose of this report is to summarize scientific progress related to ecosystem restoration in the Everglades Agricultural Area (EAA). The report discusses completed and ongoing work and identifies future scientific priorities for the EAA. The report emphasizes approaches that concurrently benefit the ecology and agriculture of the EAA.

Several classes of organic, or muck soils exist in the EAA. However, about 87% of these soils are composed largely of decomposed sawgrass (*Cladium jamaicense* Crantz) and may contain more than 85% organic matter. Soon after draining, scientists noted that these organic soils were subsiding, or decreasing in depth. This report identifies soil subsidence as the major ecological issue within the EAA, and as the major obstacle for achieving a sustainable agriculture in the EAA.

Soil subsidence is caused by physical, chemical, and microbiological processes. Although research is needed to further clarify its contribution to subsidence, oxidation of soil organic matter probably causes most of the subsidence now occurring in the EAA. This oxidation is caused primarily by microorganisms that thrive under aerobic conditions. As a result of the oxidation process, insoluble carbon portions of the organic matter convert to gaseous and water-soluble products. With this conversion of carbon comes the resulting loss of soil mass.

Scientists have advised EAA growers since at least the 1940's that to increase the longevity of their agriculture, they must reduce the rate of subsidence. The most practical means of reducing subsidence is to maintain water tables as close to the soil surface as possible; the more soil within the profile that is inundated, the less oxidation occurs. Historically, this water-table management strategy has not professed to control subsidence completely with conventional agriculture of the EAA, only to reduce the rate of subsidence. Subsidence rates in the EAA have averaged about 3 cm per year. However, due to changes in water-table management, the annual subsidence rate in the EAA now is probably less than 3 cm.

Scientists have experimented with alternate crops that could be grown under conditions that would completely control subsidence. Although they present a biological solution, these crops would not be practical because they do not have sufficient markets to warrant their commercial cultivation. Research attempting to improve yields and expand markets of these crops should be encouraged.

Sugarcane (a complex hybrid of *Saccharum* spp.) is the predominant crop in the EAA. A successful sugarcane industry depends upon a large infrastructure. Factories to convert the juice of sugarcane to raw and refined sugar; trucks, trains, railroad tracks, tractors, and wagons to transport the sugarcane from the fields to the factories; and in uses of sugarcane by-products, such as to generate electricity for public utilities, form a portion of this infrastructure. South Florida faces severe economic consequences if ecological restoration means fragmenting EAA agriculture or changing it from a predominantly sugarcane agriculture.

Much of this document describes approaches in agricultural management and research whose ultimate goal is to have no subsidence in the EAA. Improvements or changes in the hydrological system with changes in priorities for its management may be necessary to reach this goal. Past strategies to control subsidence proposed only partial control measures or use of crops not yet profitable. The research to control subsidence presented here proposes to completely control subsidence while cultivating sugarcane and other crops now grown profitably in the EAA.

Growers have already made important changes by including rice (*Oryza sativa* L.) in their sugarcane rotations, increased use of summer floods, and growing all their crops at higher water tables. A scenario is illustrated that in the short term would reduce subsidence rates from a theoretical 3.66 cm per year to 1.04 cm per year. This major improvement could be achieved by summer flooding about 77,000 ha, 37% of the cropped EAA, and growing sugarcane with water tables at 30 cm from the soil surface. Research is needed to identify sugarcane cultivars adapted to a 30 cm water table. Past research presents an optimistic outlook for quickly identifying such cultivars.

Further improvements would be more long term and gradual, but previous research suggests that chances for success are good. The major needs for long-term research are to breed and select sugarcane cultivars adapted to water tables closer to the soil surface, determine stages of growth and height of water above ground at which flooding does not harm sugarcane, determine duration of flood sugarcane can withstand without yield loss, and determine proper management of alternate flooding and moderate draining that would not harm sugarcane while not permitting oxidation. Research on rice should aim to extend flood duration by planting and harvesting it under flooded conditions. A standard condition of publicly supported genetic research on all EAA crops should be to identify cultivars adapted to higher water tables and less phosphorous fertilizer.

Since the South Florida Ecosystem is massive and contains diverse regions, it is generally agreed that the restoration process must be holistic and adaptive. The approach identified here for the EAA meets both requirements. It is holistic because it would benefit both the EAA subregion and the ecosystem. It does so by proposing an agriculture that is managed to take advantage of natural weather patterns and hydrology. Doing so would help control subsidence and permit more water storage in the EAA. Potential benefit to the natural system would be the increased ability for water to flow south according to more natural hydroperiods, and decreased need to release water in east or west outlets from Lake Okeechobee. The approach is more adaptive than other solutions proposed for the EAA, such as publicly acquiring the EAA or constructing flowways within the EAA.

Phosphorous runoff from the EAA has received more attention than other EAA-related issues. Reviewing published and ongoing projects on phosphorous runoff shows that much excellent and complex work has been accomplished and major gains have been made. A workshop was held on April 14, 1994 in Belle Glade, FL at which participants identified key concerns related to the phosphorous issue.

The workshop summary in this report shows that the issue is complex and multidisciplinary. The workshop summary does not prioritize research strategies. Further attempts at summarizing progress related to phosphorous should include teams of multidisciplinary scientists.

The final section of the report summarizes sources of scientists and funding to continue the South Florida restoration process in the EAA. Three public sources with research scientists in place in or near the EAA are the South Florida Water Management District, the University of Florida's Everglades Research and Education Center (EREC), and the USDA-Agricultural Research Service's Sugarcane Field Station. Private agricultural enterprises already have full-time scientists working on ecosystem-related issues and several scientists have worked as consultants on these issues. In addition to these sources for scientists and funding, the Environmental Protection District and the Florida Sugar Cane League, Inc. are possible sources of funding. Other important public sources of technical support include the Cooperative Extension Service, the USDA-Soil Conservation Service, and the Palm Beach Soil and Water Conservation District.

BACKGROUND

"Even if the Army Engineers' project were a physical reality today, a thousand problems would remain to be solved. These will be problems in human relations, in the interplay of economic and political forces--all affected by what is done about water in the Everglades." (Fred C. Elliot, Chief Drainage Engineer of the Everglades

from 1912 to 1931, in Bellamy, 1948). Elliot's prediction has remained accurate. However, as we search for ways to sustain natural ecosystems and agriculture, and provide for urban needs, many of the most powerful solutions can be beneficial to many needs.

In 1949, the U.S. Government initiated the Central and Southern Florida Flood Control and Other Purposes Project. The Everglades Agricultural Area (EAA) evolved from this and other earlier drainage projects (Anderson and Howell, 1993). This project intended to improve flood control and water supply, protect remaining wetlands, and reduce saltwater intrusion (Cooper, 1989; Science Sub-Group, 1993). This project altered the natural ecosystem, but also tried to preserve natural sections of the ecosystem. Urban and agricultural influences on the ecosystem were expected to expand as a result of the project, but it was hoped that the ecosystem would still sustain.

Gradually, as species became endangered, several invasive non-native species dominated natural portions of the South Florida landscape, and organic soils in the EAA were subsiding, it became clear that the ecosystem was no longer sustaining. Through the Interagency Task Force, the Federal Government is now evaluating processes to restore the South Florida Ecosystem. The purposes of this report are to summarize important scientific work related to ecosystem restoration already accomplished and ongoing in the Everglades Agricultural Area (EAA) and to identify scientific priorities for the EAA.

The Federal Government may use the South Florida Restoration initiative as a test case or a national model for ecosystem restoration (Brown, 1994; Gifford, 1994; and Kenworthy, 1994). This model must emphasize that sustainable ecosystems can contain sustainable agricultural systems, and that improvements for agriculture or for the natural ecosystem do not have to be at each other's expense. In so doing, we should follow the advice of Porter et al. (1991) and strive to make the EAA an international model of cooperation for concurrent environmental and agricultural progress.

The goal of Whalen et al. (1992) for the EAA was to "Maintain a viable agricultural production area and ensure that adequate quality and quantity of water are discharged from the EAA to protect and improve the natural resources of the Everglades Protection Area." They had previously defined the Everglades Protection Area as (Water Conservation Area) WCA-1, WCA-2, WCA-3, Everglades National Park, and the Loxahatchee National Wildlife Refuge. The goals of this report are to summarize past and current science, and to propose future scientific emphases with a similar goal to that of Whalen et al. (1992). However, this document emphasizes different subject areas than that of Whalen et al. (1992). For a more complete picture of the EAA, understanding the approach of Whalen et al. (1992) is essential.

An important change in the goal of this document compared to that of Whalen et al. (1992) is that "sustainable agriculture" replaces "viable agricultural production." Haberen (1994) stated what sustainable agriculture must accomplish: "Farming must be done in a way that guarantees a certain level of food supply for generations to come." Sustainable agriculture was defined by USDA (1994) as an "Integrated system of plant and animal production practices having a site specific application that will, over the long term: (1) satisfy human food and fiber needs; (2) enhance environmental quality and the natural resource base upon which the agricultural economy depends; (3) make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; (4) sustain the economic viability of farm operations; and (5) enhance the quality of life for farmers and society as a whole." Sustainable agriculture in this report, refers to this USDA definition.

SOILS OF THE EAA

The predominant soils of the EAA are Histosols or organic soils, comprising 313,639 ha (Cox et al. 1988). Of these, about 205,000 ha are used for agriculture (Anderson and Howell, 1993). These soils range from 33 to more than 85% organic matter in the upper 21 cm of their profiles (Zelazny and Carlisle, 1974). A summary of these organic soils was given previously (South Florida Water Management District, 1992 pages 99-106, Supporting

Information Document). More detailed descriptions are in Snyder (1994), Snyder et al. (1978), Snyder (1987), and Anderson (1989).

Due to their large amounts of organic matter, many agricultural practices routinely used on mineral soils are not successful on organic soils. These soils also pose challenging scientific issues related to sustainable agricultural and ecological systems. This report concentrates on subsidence and soil phosphorous characteristics.

Lucas (1982) described organic soil formation and Snyder (1994) described the formation specifically for the organic soils of the EAA. Immediately underneath the EAA soils lie rocks of variable qualities. At places, the rocks form a hard limestone, but more often a grayish-white calcareous mud. Generally, water does not move beneath this layer. For the soils that formed from the sawgrass sedge (*Cladium jamaicense* Crantz), Miller (1918) reported that seven weights of sawgrass were required to produce one weight of organic soil. McDowell et al. (1969) estimated that soil formation from sawgrass began about 4,400 years ago. They estimate that it took about 800 years to form the first 7.6 cm of a marly-muck on top of the bedrock. After this beginning, they estimated that soils accreted at the rate of about 8.4 cm per 100 years until they were drained.

SUBSIDENCE

Soil subsidence is the loss of depth of soil. In the organic soils of the EAA it is caused by physical, chemical, and microbiological processes. Physical factors causing subsidence include loss of buoyancy, compaction, and shrinkage due to drying. This is generally an initial phase of subsidence that occurs soon after draining. Although soil depth is lost due to these processes, soil is not lost. The microbiological cause of subsidence is due to oxidation of organic matter. When flooded, the organic matter of the EAA soils is protected from aerobic microbiological activity.

Once drained, the rate of microbial oxidation of the carbon reserves of the organic matter increases drastically. Cox et al. (1988) identified the responsible microorganisms as fungi, bacteria, and actinomycetes. This oxidation causes insoluble carbon portions of the organic matter to convert to gaseous and water-soluble products. With this conversion of carbon comes the resulting loss of soil mass (Tate, 1980b). Soil losses due to fire, and wind and water erosion may also occur, although these have not been well quantified. The controlled burning of sugarcane (a complex hybrid of *Saccharum* spp.) prior to harvest does not cause subsidence because the fire generally does not spread to the soil.

Subsidence is the most important ecological concern of the EAA (Science Sub Group, 1993). All other restoration matters related to the EAA must revolve around the subsidence of its organic soils. To achieve a sustainable agriculture, subsidence rates must be reduced to lengthen the agricultural life of the EAA and to help resolve complex issues facing the natural portions of the South Florida Ecosystem. Therefore, the goal of research in the EAA related to achieving sustainable ecosystems should be to achieve a zero-subsidence agriculture.

Disagreement exists as to what extent of the subsidence occurring in the EAA is due to oxidation. Neller (1944) determined that oxidation and total soil loss were directly related. Stephens and Speir (1969) estimated that oxidation may account for as little as 55% and as much as 75% of the total subsidence in the EAA. Volk (1973) reported that oxidation accounted for 58 to 73% of the subsidence of organic soils in the EAA. Tate (1980) noted that 85% of the subsidence for Histosols in the western Netherlands during the past 1000 years was due to oxidation. Future research should generate models specific to the various organic soils of the EAA that relate water table, temperature, and other important factors to percentage of ongoing subsidence due to oxidation. Losses not occurring due to oxidation are probably due to erosion from wind, water, and uncontrolled burning. Subsidence without soil loss may also occur due to compaction by heavy machinery. Subsidence due to these other causes needs to be quantified.

References to subsidence of the soils in the EAA began at least as early as 1942 (Clayton et al. 1942). Reports continued (Neller, 1944; Mowry and Bennett, 1948; and Allison, 1956) and by 1951 Stephens and Johnson (1951) published predictions on rates of subsidence for EAA soils. Stephens and Speir (1969), Johnson (1974), Stephens et al. (1984), and Smith (1990) reported that these 1951 predictions were on target. However, the predictions by Stephens and Johnson (1951) and Stephens and Speir (1969) that subsidence would end profitable agriculture in large areas of the EAA by 1990 and almost completely from the EAA by 2000 were not correct. These predictions assumed that as soil depths ranged from 30 to 100 cm, agriculture would become uneconomical. However, resourceful growers in the EAA are already successfully farming soils with these shallow depths.

Cox et al. (1988) reported that subsidence rates may be slowing down. Possible causes for reduced subsidence rates are proportionately more soil remains inundated, a greater percentage of the remaining organic matter is more resistant to microbial decomposition, and a greater percentage of the soil becomes mineral rather than organic as subsidence continues. From the same data source, Stephens and Johnson (1951) and Shih et al. (1977a) reported that subsidence rates in sugarcane were 70 to 75% of those found in pasture or vegetable crops when all three crops were held at similar water tables. It has been suggested that the decrease in subsidence could be caused by toxins released by sugarcane roots, lower soil temperatures with sugarcane compared to other crops, or other factors. The steady growth in area in sugarcane in Florida since 1966 when Hebert (1967) reported 76,950 ha to its latest reported level of 179,480 ha (about 155,000 ha in EAA) (Glaz, 1994) may have helped slow subsidence rates.

Snyder et al. (1978) estimated that an organic soil that began with a 3.04 m depth would eventually subside to about 7.6 to 10.2 cm of mineral matter above the bedrock if subsidence continued without control. This is clearly not desirable for agriculture or the ecosystem, which under its natural state accreted muck soils slowly.

Subsidence does not occur at uniform rates on all organic soils of the EAA. Snyder et al. (1978), McCollum et al. (1978), and Cox et al. (1988) reported seven categories of muck soils in the EAA. The Torry muck series accounted for about 7% of EAA muck soils. Its mineral content ranges from 30 to 70%. Due to this relatively high mineral content, its rate of subsidence is lower than that of other organic soils in the EAA. Terra Ceia, Pahokee, Lauderhill, and Dania mucks comprised 86.8% of the EAA in 1988. These are the soils in the EAA that are composed largely of decomposed sawgrass. These four soils have similar chemical properties and often contain more than 85% organic matter. The principal distinguishing characteristic among these four soils is depth to bedrock, Terra Ceia is the deepest and Dania is the most shallow. As subsidence progresses, a Terra Ceia gradually become a Dania muck. By reversing subsidence, or accreting soil, a Dania muck would eventually become a Terra Ceia muck. Okeechobee mucks accounted for 2.6% of the area. These soils have an underlaying horizon of peat[1] under their surface layer of muck. Okeelanta mucks comprised 3.6% of the area. These soils have a 40 to 101 cm horizon of muck on top of a fairly extensive horizon of sand. Snyder (1994) presented a comprehensive summary chapter of these soils.

The latest estimates of the percentages of Terra Ceia, Pahokee, Lauderhill, and Dania mucks were supplied using ground-penetrating radar by Collins et al. (1986) and Cox et al. (1988). The most important monitoring program for the EAA is that of monitoring subsidence. We must determine current soil depths and set up a monitoring program that will annually measure soil depths. As we strive to develop farming systems with lower rates of soil loss, this monitoring would indicate the degree of success of such systems.

Stephens et al. (1984) gave equations for estimating rates of subsidence. One equation related rate of soil subsidence to average water-table depth and another linked the combined effects of soil temperature and water-table depth on subsidence. Browder and Volk (1978) designed a systems model to test different management practices for slowing the rate of subsidence. Several studies on soils in the EAA have described its oxidation processes at

[1]Peat and muck are sometimes used interchangeably. Here, they refer to stage of vegetative decomposition, a muck being more decomposed than a peat.

the microbiological level (Duxbury and Tate, 1981; Tate, 1976, 1979a, 1979b, 1980a, 1980b; Terry, 1980; and Terry and Tate, 1980). All of these studies have left us with the general knowledge that rates of subsidence are less with cooler temperatures and higher water tables.

Insufficient agronomic work has tested these general principles to reduce subsidence rates, although Stephens and Johnson (1951) emphasized the need for such work as early as 1948. Jones (1948) advised "Strict regulation of the water table is desirable on cultivated areas of Everglades peat--that is, the water table should be low enough during the growing season to permit the crop to develop but high enough to prevent avoidable oxidation and subsidence of the peat."

Almost all EAA studies that have measured subsidence have determined that it occurs at the rate of 2.5 to 3 cm per year. Stephens et al. (1984) published an equation showing how subsidence, Y, measured in cm, changed due to depth of water table from the soil surface, X, measured in cm. The equation is $Y = 0.0643X - 0.259$. Setting $Y = 3$ cm then $X =$ water table for the past 50 years $= 50.7$ cm. This would indicate that our knowledge of the effect of water-table depth on subsidence is incomplete because the EAA water table has probably averaged more than 51 cm from the soil surface during the past 50 years.

Measurements of Andreis (1976) differ from the predictions of Stephens et al. (1984). Andreis (1976) measured subsidence for 4 years, in fields growing sugarcane with average water-table depths of 48 and 94 cm. These fields had only been cultivated for 3 years prior to this experiment. He reported annual rates of subsidence due to oxidation of 3 cm at the 94 cm depth and 0.8 cm at the 48 cm depth. Stephens et al. (1984) formula would yield a subsidence rate about 3.75 times more than that measured by Andreis (1976).

Some indirect evidence and small amounts of direct water-table measurements exist for the EAA. Gill et al. (1979) identified high water table as 30 cm and water tables in commercial sugarcane fields as ranging from 90 to 120 cm from the soil surface. Andreis (1976) described 50.8 cm as a high water table and 91.4 cm as a low water table. Kang et al. (1986) identified a normal sugarcane water table as 56.2 cm and a high water table as 29.8 cm. CH_2M Hill (1978) measured one sugarcane field's water table for 15 months and reported an average depth of 63.5 cm from the soil surface. From 1981 through 1983, water-table measurements were taken at three locations, two Lauderhill mucks and one Terra Ceia muck. During this 3-year period, the average depth was 57.1 cm (Glaz, unpublished data, 1983). Izuno et al. (1991a) reported an average 21 month water-table depth of 62 cm in one field. Coale et al. (1994a) reported an average 60 cm water-table depth in their 2-year study.

This limited evidence suggests that since 1976, average water tables in commercial sugarcane fields have ranged from at least 56 cm to more than 91 cm. According to the Stephens et al. (1984) equation, subsidence would have occurred at these water tables at rates of 3.34 to 5.59 cm per year. These rates are higher than measured rates. A research priority is to predict subsidence rates at various water-table depths for the seven classes of organic soils in the EAA. Casual observation would suggest that growers in the EAA have maintained water tables closer to the soil surface during the past two years than they have in previous years.

Agronomic Research to Control Subsidence

This section proposes research and management strategies for maintaining a profitable agriculture and controlling subsidence in the EAA. Simply because management strategies are mentioned does not mean that private companies in the EAA will be able to implement them immediately. A general management strategy over large land areas takes time to implement, and unforeseen obstacles often impede progress. Undoubtedly, growers and researchers will need interdisciplinary approaches to overcome hydrological and other issues resulting from implementation of the proposed strategies. A research strategy is just that, a research strategy. If scientists already knew the answers to research problems, there would be no need for research. Therefore, farmers will not adopt new practices simply because they are being researched.

Successful farming involves more than correct applications of biological and hydrological principles. It also depends on the prices farmers obtain for their products. For long terms, we cannot predict or even approximate many of the prices and markets of many potential agricultural products biologically capable of growing in a sustained manner in the EAA. However, we are always faced with limited resources for research. Therefore, we must choose which crops hold the most potential for being part of a sustainable agriculture in the EAA. Research should concentrate primarily on these crops. Nonetheless, we should not rule out other crops. Many uncontrollable events that affect markets can occur. Therefore research on promising alternate crops should be maintained at moderate levels.

Perhaps there are three reasons why pursuing a zero-subsidence agriculture in the EAA, equally profitable to the current, has received insufficient attention. First, is the perception that a zero-subsidence agriculture must involve continuous flooding. Second, since the endeavor is perceived as a long-term, high-risk project, those concerned about natural portions of the ecosystem tend to prefer seemingly quicker remedies which usually involve fragmenting agriculture in the EAA. Third, many contend that hydrologically we cannot meet this goal. Some argue that there is not sufficient water, others contend that pumping capability is not sufficient to prevent damaging agricultural floods.

Previous research neither categorically refutes nor supports these general opinions. The science program for the EAA must concentrate on answering these important questions.

Is Continuous Flooding Necessary to Control Subsidence?

A strong case implies that continuous flooding is not necessary to control subsidence. Predrained EAA conditions cannot be exactly determined, but evidence suggests that continuous flooding did not occur in the EAA as soils accreted. Botanists suggest that the sawgrass plain that once dominated the EAA landscape may not have occurred under continuous flooding. Zaffke (1993) reported that sawgrass tolerated ranges of inundation from 15-94%. Lowe (1983) reported that in the Upper St. Johns Basin, peaks of maximum biomass production occurred at 80-85% and 73% inundation. Lowe (1983) also cited Sincock (1958) who noted that sawgrass in the Upper St. Johns occurred most under frequency of inundation of about 45%.

With the shallower organic soils today, the Natural Systems Model of Fennema et al. (1994) predicts that the EAA would remain flooded from 300 to 360 days of a normal year in the absence of man-made structures. Since soils were up to 1.5 m deeper in the natural system, perhaps they were flooded for shorter durations.

Snyder (Personal communication, 1994) supports the theory that continuous flooding will not be necessary to control subsidence. He maintained a field in rice (*Oryza sativa* L.) for 8 to 10 months per year for 10 years. The measured soil loss for this 10-year period was less than 0.2 cm per year. This information must be used carefully. It was not collected under replicated conditions and the experiment was not repeated across locations. However, since adjacent fields subsided at rates about 15 times higher than the rice field, the flooded rice probably reduced subsidence rates substantially. The extrapolated equation of Stephens et al. (1984) predicts that a constant water table of 4 cm below the soil surface would result in zero subsidence. Brooks and Lowe (1984) theoretically predicted that saturation 60% of the time would control subsidence of organic soils of the Upper St. Johns.

Summarizing our insufficient scientific knowledge of oxidation of organic soils in the EAA permits the reasonable hypothesis that less than a continuous flood is necessary to control subsidence due to oxidation. Oxidation is caused by microbial activity mostly under aerobic conditions, and its rate increases as soil temperature increases. Questions that research need to answer are: 1. How long of a summer flood is necessary to eliminate subsidence due to oxidation? Microorganisms that cause oxidation are aerobic and temperature dependent. Research should determine relative microbial activities in summer and winter. 2. Subsequent to a flood, will these microorganisms decompose recently incorporated plant material before oxidizing the more decomposed muck soils? If so, does plowing under the nonharvested portions of a crop help control subsidence, and will doing so allow a longer time that the soil does not have to be flooded? 3. If only a summer flood is insufficient to control subsidence

caused by oxidation, how many, and of what durations, floods during the autumn, winter, and spring will control it?

Research also must determine the effects of fluctuating water tables on oxidation rates. Porter et al. (1991) stated that wetting and drying cycles increase oxidation compared to maintaining a constant water level. Broadbent (1960) and Sorenson (1974) reported increases in microbiological activity due to wetting and drying soils. However, Tate (1979b) did not find that wetting and drying increased oxidation. Stephens and Johnson (1951) reported that subsidence was lower in a "variable" 82 cm water table than in a constant 82 cm water table. In the variable water table, the water was raised to 15 cm once per week and then dropped quickly to 82 cm. These conflicting results suggest that wetting and drying can reduce or increase oxidation rates. Probably, proper management of wetting and drying cycles would produce desired results.

Short-term and Long-term Approaches

Some contend that developing zero-subsidence agricultural systems in the EAA would be too long-term and high-risk. Two reasonably safe assumptions suggest that substantial short-term, low-risk improvements in subsidence, compared to the historical rate of 3 cm per year, are attainable. The first assumption is that a lengthy summer flood will substantially reduce the rate of subsidence compared to land that is not flooded. The second assumption is that among Florida's current commercial sugarcane cultivars, some would do as well under 30 cm water tables as under current, 60 cm, water tables. The combination of expected short- and long-term gains lends itself well to the adaptive process for restoration, because changes would occur gradually.

SHORT-TERM SOLUTIONS INVOLVING RICE

The University of Florida, (Institute of Food and Agricultural Sciences (IFAS), at its Everglades Research and Education Center (EREC) has completed much research that has helped establish rice as a summer crop in the EAA. This research has studied nutritional (Anderson et al., 1987; Deren et al., 1992; Elliot et al., 1988; Elliot and Snyder, 1986; Snyder et al., 1986b; and Snyder and Jones, 1988a and b), entomological (Cherry et al., 1986; Foster et al., 1989; and Jones and Cherry, 1986), pathological (Datnoff et al., 1992), agronomic (Jones, 1993; and Jones and Snyder, 1987), economic (Alvarez et al., 1989), and water use (Shih et al., 1982; and Shih et al., 1983;) issues. The latest census indicated that the 10-year average rice hectarage in Florida was 5,030 ha (Coale et al., 1992). However, the 1991 through 1993 average rose to 8,815 ha.

Most rice in the EAA is grown in rotation with sugarcane; some is rotated with winter vegetables. As stated above, an immediate need is to compare subsidence rates of the sugarcane-rice rotation with continuous sugarcane. These studies should also analyze subsidence with the vegetable-rice rotation. A concentrated research, education, and extension initiative aimed at further increasing rice planting in the EAA should begin immediately. The initial rationale for growing rice should be for growers who would benefit economically by its use, regardless of subsidence. After more precisely quantifying Snyder's (Personal Communication, 1994) conclusion that a summer rice crop will substantially control subsidence, then the additional economic benefit of controlling subsidence could be included among the reasons to use a sugarcane-rice, vegetable-rice, or sugarcane- or vegetable-summer flood rotation.

The expected reduction in subsidence is not the only reason that flooded rice is a logical summer crop in the EAA. In addition, rice needs water when water is abundant in the EAA, during the summer. An agricultural crop that would need to be flooded during the drier winter months probably would not succeed in the EAA due to competition for water with urban and natural needs. Any species that does poorly under hot, humid, high water table conditions in the summer should not be considered. Likewise, any species that cannot withstand the cooler and drier weather of the winter should not be part of the plan. This approach also agrees with a rain-driven restoration strategy.

One argument for not expanding rice production in the EAA is that sufficient water would not be available. Shih et al. (1982) showed that overall, and in most individual months during which rice growth is recommended, evapotranspiration of rice is less than monthly rainfall in the EAA. Jones et al. (1994) presented a table of these data. Since the EAA receives water from sources other than rainfall, water availability should not be a problem often. However, droughts may jeopardize rice production in the EAA in some years. Drained conditions for short periods may not harm rice yields, depending on stage of rice growth when the drought occurs. However, long periods not flooded would lower rice yields. To compensate for changes in agriculture that will allow agriculture to help enhance the ecosystem, the restoration process must devise hydrological systems capable of maintaining EAA rice flooded during at least moderate summer droughts. These hydrological safeguards would also promote the ecological benefit of controlling subsidence.

Jones et al. (1994) discussed other positive environmental effects of rice: (1) Less nitrogen would be released by mineralization. (2) Like sugarcane, rice requires low fertilizer levels and produces well with residual nutrients of previous crops. Thus, rice, like sugarcane, could act as a buffer to help reduce nutrient runoff from the EAA and thereby help maintain the current level of winter vegetable production.

Rice can have a substantial positive impact as the EAA evolves to an agriculture that contributes positively to the ecosystem. However, rice should not be regarded as a panacea for the EAA. As discussed later, hydrologically, a monoculture of rice in the EAA may pose problems. Biologically, rice is almost entirely planted in rotation with sugarcane in the EAA. This means that a field is not planted with rice more than once every 4 years. Datnoff (Personal Communication, 1994) cautioned that the major reason that rice sheath blight, has not become a serious disease in Florida is that rice is not grown continuously on the same land. Also, rice can be grown without added fertilizers because it uses residual fertility of other crops. Rice would lose this advantage if grown in monoculture.

A critical area for rice research is harvest technology. About 50% of EAA growers harvest rice twice from the same planting. They harvest initially from 115-135 days after planting. Then, from 75 to 85 days later they harvest a ratoon crop. They drain their fields before each of these harvests. Often due to excessive rainfall and to meet harvest schedules, fields are drained rapidly, and left drained for about 14 days.

Temporarily draining rice fields may reduce the effects of flooding on reducing soil subsidence, although this needs to be verified and quantified. Draining may also increase phosphorous export from farm fields to canals. Studies like those of Izuno (Personal Communication, 1994), of water management systems that allow draining water from some fields onto others should continue. Another approach, which would favor both the phosphorous and subsidence issues is to develop rice harvesting equipment that would allow growers to harvest rice while it remains flooded.

Growers in the EAA typically plant rice on drained fields, and wait at least 3 weeks until the rice plant is tall enough before flooding. Water control must be precise when the rice is first flooded because if water covers these young rice plants, they will die. In other rice growing regions rice seed is applied by air to flooded fields. When germinated like this, the young rice plant can survive even though it is submerged. Since this could include at least 3 extra weeks of flooding, research to make this practice feasible in the EAA is needed. Perhaps before this research is initiated, research should first determine the effect of the 3 extra weeks of flood on controlling subsidence.

Short-term increases in rice hectarage in the EAA should be achievable without major changes to sugarcane or vegetable systems or losses in farm profitability. In 1993, sugarcane occupied 179,480 ha in Florida (Glaz, 1994) and about 155,000 ha in the EAA. Sugarcane is typically planted and then harvested annually three times. The first harvest is called the plant-cane harvest and the last two harvests are called ratoon harvests.

Sugarcane growers in Florida plant sugarcane under successive and fallow planting systems. In the successive system, growers plow out and replant their fields immediately after the last-ratoon sugarcane harvest.

In the fallow system, growers wait almost one year until the following sugarcane planting season to replant their fields with sugarcane. During the 1991-93 seasons, growers planted 31.5% of their sugarcane under the fallow system and 68.5% under the successive system (Glaz, 1994). Fields planted in the fallow system can be cropped to something other than sugarcane one out of every four summers (Table 1). Rice has become an increasingly popular use of this fallow land.

Table 1. Fallow and successive sugarcane planting systems.

Year	System	Activity
1 Summer	Fallow	Land idle or planted to alternate crop
1 Fall	Fallow	Plant sugarcane
2	Fallow	First sugarcane harvest (plant cane)
3	Fallow	Second sugarcane harvest (first ratoon)
4	Fallow	Third sugarcane harvest (second ratoon)
5 Summer	Fallow	Land idle or planted to alternate crop
1	Successive	Harvest sugarcane, plow out stubble and plant sugarcane
2	Successive	First sugarcane harvest (plant cane)
3	Successive	Second sugarcane harvest (first ratoon)
4	Successive	Third sugarcane harvest (second ratoon)
5	Successive	Harvest sugarcane, plow out stubble and plant sugarcane

Assuming that growers plant about 54,000 ha of sugarcane annually as they did in 1993 (Glaz, 1994), and 31.5% is planted in the fallow system, about 17,000 ha are available for rice each summer. Snyder et al. (1986a) found that sugarcane following rice had increased yields of 2.2 metric tons sugar per ha compared to sugarcane planted in fields not flooded during the summer fallow. Some of this yield increase may have been related to the insect and nematode control of flooding rather than rice, but this was not determined. Growers in the EAA are growing rice in this system on less than 50% of the available land. A research and extension effort should determine why rice is not planted on 100% of these 17,000 ha annually.

A second opportunity exists to increase the sugarcane-rice rotation. Alvarez (1994, Personal Communication) reports that an economic analysis is underway which among other things is comparing successive sugarcane with the sugarcane-rice rotation. Glaz and Ulloa (1993) reported that successive yields averaged from 14 to 17 metric tons cane per ha per year less than nonflooded fallow yields for a three-crop cycle (plant crop through second ratoon). The successive rotation is popular because although yields per ha per year are lower, sugarcane is harvested more years than in the fallow system (Table 1). In a sugarcane-rice rotation, cane yields following rice are higher than cane yields following nonflooded fallow (Snyder at al. 1986). Therefore, yields would probably increase more than the 14-17 metric tons cane per ha for sugarcane following rice compared to the sugarcane following nonflooded fallow reported by Glaz and Ulloa (1993). Once the economic study is released, if it is necessary and appears reasonable, researchers should make a concentrated effort to improve the profitability

of the sugarcane-rice rotation to at least make it equal to the successive-sugarcane system. By doing so, an additional 37,000 ha could be cultivated with rice, and thereby summer flooded.

A third opportunity exists to increase rice hectarage in the EAA. It is difficult to estimate the area grown to winter vegetables in the EAA because many vegetable growers harvest more than one crop per year. Schueneman and Sanchez(1994) estimate that the EAA contains about 23,100 ha dedicated to winter vegetables. A small amount of this land is already rotated with rice. Some of the hectarage not planted to rice is left fallow during the summer and some of this fallow land is flooded during the summer.

Many vegetable growers flood for 6 weeks, drain for 2 weeks, and then flood again for 6 more weeks during the summers. This practice has probably evolved from Genung's (1970) work that determined that flooding for 4 weeks, draining two weeks, and reflooding for 4 more weeks provided 100% wireworm control. Later work by Hall and Cherry (1993) reported that more than 6 weeks of continuous flooding would be needed to provide 100% mortality of wireworms.

Research should determine the differences in annual subsidence in fields drained for 2 weeks compared to those flooded for 14 consecutive weeks during the summer. During summer fallow periods, the growers' primary goal should be to control subsidence rather than wireworms. The control of wireworms and other pests should be considered as an extra benefit of controlling subsidence.

Schueneman and Sanchez (1994) discussed the cropping seasons for many EAA vegetables. More vegetable growers could probably include a rice crop without upsetting their vegetable cropping patterns. Agronomic research aimed at reducing growing seasons and time needed for land preparation for both vegetables and rice could help accommodate this cropping sequence. Successful results could increase annual profits for these growers as they reduce soil subsidence.

By using the sugarcane-rice, vegetable-rice, and sugarcane- or vegetable-flooded fallow cropping systems, growers in the EAA could flood much of their soils during the summer. If one only considers the fallow sugarcane cropping system and the summer-fallow of vegetable fields, 40,000 ha could be flooded each year. Thus, immediately, 19.5% of the EAA could be flooded during the summer wet season. Growers who could include a rice crop into their cycles may increase their annual profits on much of this land. Replacing successive sugarcane with a sugarcane-rice rotation would allow flooding of 37,000 additional ha during the summer rice crop. This would allow flooding of 37.5% of the total agricultural land in the EAA during the wet season. This scenario is low-risk because it uses cropping systems already proven profitable, and emphasizes maintaining or increasing current profits.

As stated earlier, an important research topic related to this approach is the annual rate of subsidence with the sugarcane-rice rotation vs. only sugarcane and the vegetable-flooded fallow or vegetable-rice rotation vs. only vegetables. Optimistically hypothesizing that the annual subsidence rate with these flood cropping systems will approach zero, results in a 37.5% reduction of subsidence in the EAA, or a reduction from 3.6 to 2.25 cm per year (Fig. 1). This analysis was based on 205,000 cultivated ha per year in the EAA; 155,000 ha of sugarcane, 17,000 ha of fallow sugarcane land, 23,000 ha of vegetables, and 10,000 ha of sod, and an initial subsidence rate of 3.6 cm per year based on a 60 cm water table and the Stephens et al. (1984) equation relating subsidence and water table.

Some growers have already initiated these strategies in the EAA, so the annual subsidence rate is probably substantially lower than 3.6 cm. Also, the Stephens et al. (1984) equation may overestimate subsidence rates, as discussed earlier. Therefore, this analysis of theoretical subsidence rates should be used to demonstrate relative differences in subsidence with various strategies rather than as a precise estimate of EAA subsidence.

SUGARCANE

The ecological and economic benefits of sugarcane to South Florida are often poorly understood. Even within the South Florida area, where sugarcane has extensive positive economic impacts, it often has less than a positive image. One possible reason is the misconception that sugar, the primary product of sugarcane, is bad for one's health. However, research has shown that unless one suffers from an illness such as diabetes, consumption of sugar at levels common to the U.S. population has no negative health effects except that it contributes to dental caries (Glinsmann et al. 1986).

Sugarcane growers also enjoy less than a harmonious public relationship with groups concerned about restoring natural portions of the South Florida Ecosystem. The news media often reports demands that sugarcane be removed from the EAA or that sugarcane growers pay directly for all negative environmental impacts they cause. This negative relationship is unfortunate because sugarcane can be an integral component of an ecological restoration program. Sugarcane and rice are the most ecologically sensible among the major crops grown historically in the EAA.

Although there is disagreement on its negative impact, scientists agree that more phosphorous leaves now than before widespread agriculture was practiced in the EAA. One wonders if those who suggest removing sugarcane from the EAA understand how much worse the phosphorous problem would become if growers replaced sugarcane with other EAA crops, or if agriculture was totally discontinued in the EAA. Izuno et al. (1991b) reported that less phosphorous was exported from a field cropped to sugarcane than from a field left fallow. They suggested that sugarcane acted as a nutrient sink. Although sugarcane and vegetable agriculture may have led to some of the ecosystem's phosphorous-related problems, changes in sugarcane agriculture already in place indicate that sugarcane can help resolve the problem.

Table 2 is compiled from fertilizer recommendations of Sanchez (1990) for crops historically important in the EAA. All EAA crops except rice required more phosphorous fertilizer than sugarcane. Celery, escarole, and lettuce often required about 10 times as much phosphorous per ha as sugarcane. At a soil test level of 9, escarole required 36 times more phosphorous fertilizer than sugarcane.

Coale et al. (1993) found that sugarcane removed 1.79 times as much phosphorous as was applied as fertilizer. Coale et al. (1994a) reported that sugarcane removed 23 kg phosphorous per hectare or 0.22 kg phosphorous per ton of sugarcane harvested. Andreis (1975) reported that a crop of sugarcane that yields 90 metric tons cane per hectare would contain 13.2 kg of phosphorous. In work that confirmed that of Andreis (1975), Izuno et al. (1991) found that sugarcane annually removed about 12.5 kg per ha phosphorous from the EAA. Since sugarcane accumulates biomass for a full year before its harvest, and since much of this biomass is removed at harvest, it is logical that sugarcane can be a tool for removing excess phosphorous from the EAA. Recent work has identified practices to reduce many of the high vegetable fertilizer rates. However, even at these reduced rates, phosphorous applied to vegetables is still much more than that applied to sugarcane.

Andreis (1975) also noted that sugarcane cultivars differed in amounts of phosphorous in their tissue. This lends credibility to the concept of pursuing breeding and selection programs aimed at identifying sugarcane cultivars with various phosphorous uptake capabilities. Glaz and Ulloa (1994) reported further evidence that such a breeding and selection goal could be successful. A group of USDA and University of Florida scientists have recently initiated a long-term sugarcane genetics program with this objective.

Table 2. Phosphorous fertilizer recommendations for crops grown on Histosols in the EAA across a range of soil-test-P index levels (Sanchez, 1990).

Crop	Soil-test index levels 3	6	9	12
	kg fertilizer P_2O_5 applied per hectare			
Cabbage	157	90	22	0
Celery	493	426	359	291
Endive	381	314	247	179
Escarole	605	538	471	403
Lettuce	538	471	404	336
Radish (three crops)	247	179	112	45
Radish (one crop)	112	45	0	0
Rice[a]	0	0	0	0
Sod	140	120	60	0
Sweet corn	269	202	134	67
Sugarcane	53	40	13	0

[a]The recommendation for rice by Sanchez (1990) is valid for rice grown in rotation with an adequately fertilized crop. If grown in monoculture, rice may require some phosphorous fertilization (Snyder and Jones, 1988a and 1992).

Another positive ecological characteristic of sugarcane is that it requires small amounts of pesticides. For disease problems, sugarcane growers rely primarily on resistant cultivars. Hall and Bennett (1994) estimated that in 1990, more than 60% of Florida sugarcane fields received no foliar insecticide applications and that typically soil insecticides were applied only once every 3 to 5 years. Many growers have scouting programs to help decide if insecticides are necessary. Hall (1981) recommended spraying for borer control if more than 3% of stalks had borers and less than 50% of the borers were parasitized. Hall (1990) explained that threshold determinations of wireworms rely upon more than just the wireworm population, but he recommended generally that if wireworms were less than 12,000 per ha, then soil insecticides were not needed. Some herbicides are used for weed control. However, once sugarcane covers the rows, herbicides are generally not needed. Many growers use shallow cultivation to keep herbicide use to a minimum before sugarcane growth covers the inter row space. Glaz et al. (1989) found that such cultivations were more beneficial in the second-ratoon than the plant or first-ratoon crops.

Snyder et al. (1978) reported that sugarcane could tolerate water tables as high as most crops except rice, and still produce optimum yields. Due to restoration plans, the EAA of the future may convey more water than today. Sugarcane offers more flexibility than other crops in formulating a water-management strategy to deal with wetter and sometimes drier conditions from a rain-driven system. Many vegetables and rice need constant water-tables to produce high yields of acceptable quality. At some stages of growth, water tables of 0 to 1.2 m from the soil surface for short durations probably do not harm sugarcane. Therefore, hydrologists could plan to flood sugarcane fields to store excess water and drain them when other areas need water. Also, sugarcane is primarily planted and harvested during the dry season. With proper water management, these practices could probably continue with minimal impact.

A large sugarcane infrastructure is in place in South Florida. Seven large sugar factories process sugarcane into granulated sugar. Two refineries refine the sugar. Electrical cogeneration plants, and plants for other by-products are in place and planned at several factories. Many trucks, trailers, and trains carry sugarcane to the factories. Thousands of people are employed by the sugarcane industry. We are fortunate that sugarcane agriculture offers many of the ecological solutions we seek.

The development of a profitable sugarcane cropping system with no net soil loss should be the primary goal for the EAA for those trying to conserve either the EAA and or the South Florida Ecosystem. This approach to achieving a sustainable agriculture in the EAA has not received sufficient attention from scientists, probably for three reasons. One, sugarcane is generally regarded as a crop that does not tolerate flooded conditions. Second, the perception exists that organic soils must be flooded 12 months per year to control the subsidence caused by oxidation. Third, due to increased urban water demands, the EAA may no longer have enough water to remain flooded sufficiently to end subsidence.

Can sugarcane tolerate floods?

Research has shown that sugarcane has potential genetically to adapt to a wide range of water tables. Glaz and Kang (1985) reported that relative cane production of two of 12 cultivars varied due to differing water tables. Deren et al. (1991) found that sugarcane cultivars interacted significantly with water tables for such traits as cane and sugar production. These results showed that for immediate use, some existing cultivars would be better adapted to high water tables than others. For long-term planning, these preliminary studies indicate that breeding programs could successfully identify sugarcane cultivars adapted to higher water tables.

In an experiment aimed at insect control, Cherry (1984) reported on the effects of flooding sugarcane for 10 days during September or October in commercial fields. Cherry did not compare flooded vs. unflooded fields, but reported that the flooded sugarcane fields were commercially profitable. However, to substantially reduce subsidence, sugarcane fields will need to remain flooded for longer than 10 days. A preliminary study by Deren et al. (1991) found that longer duration flood tolerance in sugarcane is probably a heritable trait, and that variability among sugarcane clones for this trait is sufficient to warrant beginning a long-term project to breed and select for flood-tolerant sugarcane. In India, Naidu and Arulraj (1992) reported that 14 of 65 cultivars were resistant to "severe conditions of waterlogging." Naidu (Personal Communication, 1994) stated that the sugarcane in these experiments was subjected to continuous flooding, at times with water 30 to 60 cm above ground level, from mid June to mid November.

In a field study testing water tables and sugarcane Kang et al. (1986) found that sugarcane at a 29.8 cm water table yielded more sugar and cane per ha than at a 56.2 cm water table. They reported a mean cane yield increase of 26.4% and an increase of 16.7% in sugar concentration at the higher water table. Gascho and Shih (1979) tested five sugarcane cultivars at water tables of 32, 61, and 84 cm from the surface of Pahokee muck soils in lysimeters. Overall, the highest yields occurred at the 61 cm water table. Two of the six cultivars yielded equal cane weights at all three water levels. Although not significantly different from the yields at the two deeper water tables, both of these cultivars had their highest cane yields at the 32 cm water table. LeCroy and Orsenigo (1964) studied cane tonnages and sugar concentrations of four sugarcane cultivars at six water table depths, ranging from 36.6 to 88.4 cm from the soil surface. All four cultivars had respectable yields at the 36.6 cm water table. In addition, they reported variable cultivar responses to water-table depth. Andreis (1976) reported that yields of a 4-crop cycle (plant crop through third ratoon) of sugarcane at a 48 cm water table equaled those of sugarcane at a 94 cm water table. Andreis further found that yields in the 48 cm water table were more favorable in the first three harvests compared to the fourth harvest (third ratoon).

In a personal communication summarizing several experiments in Louisiana (Carter, 1986; Carter and Floyd, 1970; Carter, 1980; Carter et al. 1970; Carter et al. 1992; Carter et al. 1988a; Carter et al. 1988b; Carter and Camp, 1983; Carter and Floyd, 1975), Carter (1994) reviewed water table and sugarcane relations. Floods can be maintained by stagnant or by constantly inflowing and outflowing water. Since water movement in contact with air increases the oxygen content of the water, one would expect sugarcane to do better in the moving rather than the stagnant water. Research must also determine if the oxygen in the moving water is sufficient for microorganisms to support substantial oxidation. One source for optimism comes from Andreis (1976) who reported that water had to be pumped in often to maintain water tables, but subsidence was much less than that predicted by the equation of Stephens et al. (1984). Reddy (1987) noted that flooding in organic soils can be conducive to growth

of algae. Since these algae photosynthesize which elevates oxygen, they may reduce the anaerobic conditions of the soil.

Carter (1994) also felt that consistency of water table, to a point, may be more important than depth of water table. He suggested that sugarcane may do well at water tables at 30 cm or closer to the soil surface if this water table does not fluctuate for long periods. However, Carter and Floyd (1975) also reported that high water tables would be most successfully maintained during April to October, rather than during the cool winter months. This fits well with the rain-driven approach to reducing subsidence because April to October is when water is naturally available in the EAA, and theoretically, to control oxidation, it is more important to cover soil with water during these warmer months when microorganisms are most active.

Gascho (1985) reviewed root growth of sugarcane. He reported that in one region with well drained and dry soils, sugarcane roots had been reported 400 cm deep. However, other reports cited by Gascho indicated that 60% of sugarcane roots were within 20 cm of the soil surface and more than 85% of the roots were within the upper 40 cm of soil. Andreis (1976) reported that sugarcane had greater total root weight when grown under a water table 48 cm from the soil surface compared to 94 cm from the soil surface. This vast range of root growth is undoubtedly a major reason for sugarcane's successful adaptability to a wide range of moisture conditions.

Other reports from Florida and from other regions indicate that some sugarcane cultivars adapt well to floods of at least minimum duration (Burgess, 1991; Naidu and Arulraj, 1992; Negi et al., 1971; Roach and Mullins, 1985; and Stevens, 1948). Two programs in Florida breed and select sugarcane cultivars, a cooperative program of USDA-ARS, the University of Florida-IFAS, and the Florida Sugar Cane League, Inc., and a program of U.S. Sugar Corp.

Short-term sugarcane research

The most important short-term objective should be to test current commercial-type cultivars at several water tables. Those doing best under flooded conditions could be used as parents in the long-term program, and could be utilized for biparental crosses immediately. Based on Kang et al. (1986), LeCroy and Orsenigo (1964), Gascho and Shih (1979), and Andreis (1976), some commercial cultivars may yield at least as well at a 30 cm compared to a 60 cm water table. If research identifies such cultivars, growers could use them immediately without losses in productivity. According to the Stephens et al. (1984) equation, this would reduce subsidence by 53%. Combining this with the earlier proposed gains of 37.5% reduction due to summer flooding, EAA subsidence could be reduced by 71.1% to an overall rate of 1.04 cm per year (Fig. 1). Factoring in the suggested 25% reduction in subsidence due to sugarcane, yields a theoretical EAA-wide subsidence rate of 0.78 cm per year.

Growers in the EAA have already begun many of the changes suggested here. The short-term scenario proposed in Fig. 1 with subsidence declining to 1.04 or 0.78 cm per year is not a major change from EAA agricultural conditions of today. However, achieving this type of agriculture would be a major short-term gain in maintaining a profitable agriculture and controlling subsidence in the EAA. Achieving these realistic goals would more than triple the life of EAA agriculture. If the 25% reduction due to cropping sugarcane proves factual, the life of these soils would be extended by a factor greater than four.

Long-term sugarcane research

One long-term sugarcane project should aim at breeding and selecting cultivars adapted to water tables closer to the soil surface than 30 cm. This will involve identifying parents, evaluating progeny, and quantitative genetic studies. Normal sugarcane selection cycles in Florida, from parental crosses to cultivar releases, take from 9 to 11 years. Therefore, substantial improvements in this characteristic could take many years. However, we could expect gradual improvements. We should not expect suddenly after 25 years of research to identify a sugarcane cultivar that withstands flood for 7 months. Instead, we should expect to gradually identify cultivars adapted to higher water tables for longer durations.

Some of the new breeding procedures which operate at the molecular level could complement the conventional breeding approach in producing sugarcane cultivars adapted to higher water tables. No work in this area is underway in Florida or related to producing sugarcane clones adapted to high water tables. However, the Florida Sugar Cane League, Inc. supports the International Consortium of Sugarcane Biotechnologists (ICSB). Scientists supported by the ICSB are currently doing genetic mapping (RFLP and restriction maps) and transferring of genes from other plants to sugarcane in France, Brazil, Australia, and other countries as well as Louisiana, Texas, California, and Hawaii.

These new areas of biotechnology offer enormous potential. However, concrete benefits with sugarcane would probably be very long term. With other crops whose genetics are better understood, minor gains have been achieved through molecular biology. These gains have often been due to previous genetic studies which had identified specific functions of single genes. However, sugarcane genetics are very complex and poorly understood. Effects of individual genes are unknown. Genetic studies of sugarcane are normally quantitative in nature, and even these do not fit classic Mendelian theories due to the poorly understood polyploid nature of sugarcane.

The concept of breeding and selecting sugarcane cultivars adapted to higher water tables is not new among agricultural scientists in the EAA. The work already initiated in Florida has produced promising results. To continue this work and obtain results sufficiently reliable for successful commercial production, scientists need initial funding to construct several locations with replicated plots of several water tables. Agricultural scientists in Florida have a long and unsuccessful history of seeking such funding. This list of unsuccessful proposals includes, but may not be limited to Kidder et al. (prior to 1978), Gill et al. (1979); Deren, Snyder, and Miller (1989), Deren, Snyder, Miller, and Porter (1989), Izuno et al. (1990), Deren (1990), Nuessly et al. (1990), Deren (1991a), Deren, (1991b), Deren, Snyder, and Miller, (1991a), Deren, Snyder, and Miller, (1991b), Deren, Snyder, and Miller, (1991c), Deren, Porter, and Miller, (1991), and Coale and Deren, (1992). The scientists who comprise the cooperative sugarcane breeding program in Canal Point have already modified that breeding program to the extent possible without additional support. Their immediate goal is to make all selections from the early stages of their four-stage, 9 year program at 30 cm water tables.

Equally important to the long-term breeding project is the need to do agronomic/microbiological research related to sugarcane and subsidence. Although sugarcane scientists are confident they can breed and select cultivars adapted to higher water tables, even the most optimistic researchers doubt they will find sugarcane cultivars that produce well in floods of 6 to 7 months duration. Therefore, as breeders improve water tolerance in sugarcane, agronomists/microbiologists must pursue a water-management system that will produce optimum sugarcane yields while minimizing subsidence. As breeders take sugarcane to its biological limits for tolerating flood, agronomic and microbiological work should determine the least amount and durations of flooding necessary to control subsidence while growing sugarcane profitably.

This work should begin by rigorously testing the assumption that sugarcane can tolerate floods of short duration without suffering yield losses. Concurrently with this, research should determine at what stage of growth sugarcane best tolerates floods, and changes in sugarcane production as height of water above the surface increases. Once benchmarks are determined for these characteristics, breeders can attempt to improve upon them. Work should then determine how long and to what depth water tables can be lowered before appreciable oxidation resumes. With this knowledge, scientists would then need to determine how long and to what depth sugarcane should be drained before reflooding will not harm its growth. The ultimate goal would be to determine a water-management strategy under which sugarcane would thrive, but subsidence due to oxidation would not occur. This research would also improve our knowledge about the effects of variable water tables on subsidence.

Microbiological research should also pursue the suggestion that crops such as sugarcane and alfalfa may release toxins from their roots that inhibit microorganisms from causing oxidation. The first step would be to determine if sugarcane roots release such toxins and to determine their effectiveness. If promising, geneticists could then include among their goals to identify cultivars that release more of these toxins. All of this is extremely

preliminary, but a logical research topic based upon the findings that sugarcane inhibits subsidence. If successful, this research could offer an additional mechanism for achieving a zero-subsidence agriculture in the EAA.

Other areas in which research will probably be needed are sugarcane pathology and entomology. With continually higher water tables, and roots at times submerged in water, certain pathogens that are naturally controlled under current conditions may cause economic damage. In particular, *Pythium* and *Phytophthora* species may become more abundant under these proposed wetter conditions (Personal Communication, Comstock, 1994. Extensive flooding will probably cause population changes among insect species in the EAA. Future entomological work should try to maintain favorable balances of insect pests and their predators, and try to assure that new insect pests do not emerge.

IS A CONTINUOUS FLOOD NECESSARY TO CONTROL SUBSIDENCE?

This issue was discussed previously in this report. Continuous flooding probably is not necessary to control subsidence. Much of the proposed agronomic/microbiological research would provide answers to this issue.

IS THE EAA HYDROLOGICALLY CAPABLE OF CONTROLLING SUBSIDENCE?

The third reason for not pursuing a zero-subsidence agriculture is that hydrologically, the EAA may not be capable. Hydrological issues in South Florida pose a special challenge to agriculture and restoration. The logic behind the agricultural systems proposed here is that they adapt to water conditions closer to those that would occur naturally in the EAA today. The issue is more complex however, because even without an agriculture, the EAA of today is expected to contribute to the water needs of the urban and natural sectors. In addition, agricultural crops cannot always be left to natural water conditions. When water levels stay too high or too low for too long, major economic losses may occur.

One would assume that after meeting urban and other man-related water needs, flooded conditions could exist in much of the EAA in most summers, but growers could not depend upon, and often would not want, consistently flooded conditions in winters. That enough water may not be available to flood the entire EAA every summer is one important reason that rice production must remain limited to a percentage of the area. Having a more flexible crop with regards to water requirements, like sugarcane, does not put growers at risk of economic hardship in dry summers when they cannot flood all their land due to competing needs of the natural and urban sectors of the ecosystem.

A thorough hydrologic analysis is needed for several issues. A comprehensive study using long-term weather patterns and proposed EAA water needs should determine how often to expect the EAA to have too much or too little water for the proposed agricultural systems.

A typical field in the EAA is from 14 to 16 ha, 804 m long x 196 m wide. At the front and back of each field (across the 804 m length) is a canal, often about 5 m wide. At each side of the field is a field ditch, often about 2 to 3 m wide. This configuration allows growers to manage water table levels and move water among fields. With these ditch spacings, growers expect that there will not be a substantial gradient in water table from the field ditches to the center of the field. However, disagreement exists as to what gradient exists under different conditions. This should be determined. These canals are usually connected to a primary or secondary South Florida Water Management District canal. Therefore, growers can move water from most of their fields back to District canals, and they can receive water from District canals.

Research must determine what improvements this combined public and private water management system will need to meet growers' needs to move water among fields when irrigation or drainage is urgently needed. These

needs would be more precise and often more urgent under the agricultural system proposed compared to the current system. Rahi and Shih (1979) performed part of this research by studying soil-water characteristics. Also, scientists should try to determine modifications in current water-control facilities that would enable the proposed agricultural system to deliver more and better quality water at more appropriate times to the natural portions of the ecosystem. This would help tie in the proposed agricultural system for the EAA with the holistic ecosystem restoration approach.

VEGETABLES

Schueneman and Sanchez(1994) estimate that the EAA contains about 23,100 ha of winter vegetables. As stated earlier, vegetables need much higher amounts of phosphorous fertilizer than sugarcane and rice, cannot withstand as high a water table as sugarcane and rice, and cannot withstand fluctuations in water table as well as sugarcane. Vegetable research should aim to improve these characteristics. A key advantage of vegetables is they are annual crops grown primarily during the winter dry season. Thus, most growers should be able to maintain summer floods or rice crops without compromising their vegetable crops.

Most winter vegetables in the EAA probably are not genetically capable of producing well in water tables as high as sugarcane. Still, breeders should be encouraged and supplied proper facilities to breed vegetable cultivars capable of withstanding water tables higher than those currently used. Vegetable breeding programs in the EAA currently exist at the University of Florida Everglades Research and Education Center (EREC) in Belle Glade, FL for lettuce, celery, and sweet corn. Research should also determine ways of using much of the residual phosphorous applied to vegetable fields for subsequent sugarcane, rice, or vegetable crops. Izuno (Personal Communication, 1994) currently is carrying out research in this area.

All vegetables do not receive equal amounts of pesticide applications. Radish, a crop with a rapid turn around time, rarely requires pesticides. Sweet corn may receive two insecticide applications per week after silking. Several vegetables require preventive fungicides at regular intervals, because once certain diseases successfully infect a plant, their populations can explode across fields. Within the last 15 years, scouting has become an accepted practice for insect control on many vegetable crops. This has reduced insecticide use substantially in the EAA. A research need is to more precisely determine threshold levels that could be used in conjunction with scouting for insect control. Comprehensive models that require inputs of market, biological, and environmental factors could help vegetable growers make daily decisions on insecticide use.

SOD

Cisar et al. (1994) provided a summary of sod production in the EAA. Approximately 10,000 ha (24,710 ac) of sod were produced in the EAA in 1990. This accounted for about 50% of Florida's sod production. In addition to subsidence, soil is a desirable part of the sod product. Soil loss per harvest, every 10 to 12 months, ranges from 0.6 to 1.25 cm. Differences in this range are due to type of machine used to harvest and sod and soil conditions at harvest. Water tables remain relatively high in sod, from 30 to 76 cm from the soil surface. Probably the sod could withstand higher water tables, but the soil is not sufficiently firm to support heavy machinery used for mowing as the water table gets above 30 cm. As shown in Table 2, phosphorous fertilizer required for sod is not as low as for sugarcane and rice, but not as high as many of the EAA vegetable crops.

Research priorities to make sod production more sustainable include development of harvesters that extract less soil, determination of harvesting conditions that extract the least amount of soil, development of machinery capable of mowing at higher water tables, development of more flexible mowing schedules to lessen the constraint of mowing on water-table management, and water table management that permits higher water tables during periods requiring less frequent mowing.

ALTERNATE CROPS

The major thrust of research in the EAA should be to make current commercial crops more ecologically compatible without losing profits. However, research on alternate crops should not be ignored. Perhaps a market will never develop for some of these crops. On the other hand, market conditions may change for crops now grown in the EAA. Also, crops grown in monoculture often develop serious pest problems. Sugarcane has developed disease, insect, and weed problems. Pathologists, entomologists, agronomists, and geneticists often plan much of their research around these issues. Based on other rice-growing areas, rice as a monoculture may present more serious pest problems than those of sugarcane. Research on alternate crops should concentrate on crops similar to rice that thrive under flooded conditions during EAA summers, but would not suffer devastating yield losses if not flooded for short durations. Also, research should concentrate on crops whose estimated evapotranspirations do not exceed long-term average EAA rainfall.

Alternate crops may individually never account for large amounts of EAA area. However, if growers develop small markets for several crops, perhaps as a group the alternate crops could play an important role. Jones et al. (1994) summarize work on water spinach, water celery, taro, Chinese water chestnuts, and lotus. These crops have grown well experimentally in the EAA. To grow them commercially, they would need expanded markets. Wild rice may already have a sufficient market for some commercial production, but available cultivars do not yield at commercially profitable levels in the EAA. Jones et al. (1994) suggest that breeding work for wild rice cultivars adapted to the EAA. Taro, alemangrass, and paragrass offer potential as biofuel crops if prices of present sources of fuel rise.

PHOSPHOROUS AND AGRICULTURE IN THE EAA

LOTAC I (1986) reported that phosphorous from agricultural drainage was a contributing factor to the accelerated eutrophication of Lake Okeechobee. Canfield and Hoyer (1988) and Maceina and Soballe (1990) however, proposed that the noted eutrophication was due to causes other than agricultural drainage. Another concern was that elevated phosphorous levels in areas of Water Conservation Areas (WCA's) near entry points of agricultural drainage water were causing an unnaturally high level of cattail (*Typha latifolia* L) growth compared to sawgrass (*Cladium jamaicense* L.) (LOTAC II, 1990). The South Florida Water Management District (1992) cautions that several factors can influence expansion of cattails in the Everglades. Among these are "physical disturbance of underlying soil profile (by canal construction activities or by alligator nest building), proximity to seed sources, fire, hydrologic changes and the availability of nutrients."

Reddy et al., (1993) and Whalen et al., (1992) stated that EAA drainage waters entering the Loxahatcheee National Wildlife Refuge contained up to twenty times higher phosphorous concentrations than those measured at interior sites within the Refuge. They further stated that drainage from the EAA accounted for 47% (205 metric tons per year) of all phosphorous flowing into the system and that rainfall accounted for an additional 40%. Anderson and Howell (1993) calculated theoretically that the EAA was responsible for 51.9 metric tons of phosphorous per year transported to the Everglades Protection Areas which include Water Conservation Areas (1, 2A, 2B, 3A, and 3B), the Arthur R. Marshall Loxahatchee National Wildlife Refuge, and Everglades National Park.

Two major programs are in place to deal with lowering phosphorous content of EAA drainage water entering Water Conservation Areas. One is the use of Best Management Practices (BMP's) pursued by the University of Florida-IFAS and private growers. This IFAS work receives much support from the Environmental Protection District. The other program is determination of the utility of up to 16,200 ha of Storm Water Treatment Areas (STA's) as described by Whalen et al. (1992). The South Florida Water Management District is responsible for this work.

Soil subsidence is potentially a major source of phosphorous in agricultural drainage waters coming from the EAA (Hortenstine and Forbes, 1972). Morris (1975) estimated that subsidence generated 87 kg P per ha per yr, or 400% of the average rate of fertilizer phosphorous applied to sugarcane (Sanchez, 1990). Reddy (1987) reported that oxidation causes release of from 38 to 185 kg phosphorous per ha per year. Therefore, controlling subsidence and phosphorous should generally be consistent objectives. However, in the short-term, phosphorous runoff may increase due to control of subsidence (Sanchez and Porter, 1987). For the long-term, scientists must determine effective phosphorous control strategies within the framework of an agriculture with substantially less subsidence.

Background levels of soil phosphorous in organic soils cropped to sugarcane ranged from 90 to 330 mg phosphorous per liter (CH_2M-Hill, 1979). This range encompasses the average values for organic soils of 0.01 to 0.3% of the soil reported by Lucas (1982). Diaz et al. (1993) reported phosphorous levels of 279 μg phosphorous per cm^3 of soil for an uncultivated Pahokee muck. They reported similar levels for cropped Pahokee and Lauderhill mucks. For an Okeelanta muck they reported 156 μg phosphorous per cm^3 and for a Torry muck 1737 μg phosphorous per cm^3 of soil. Reddy (1983) reported that Florida's central and southern organic soils released from 16-168 kg phosphorous per ha into effluent. This accounted for 0.75 to 1.1% of the total soil phosphorous of the organic soils in Southern Florida. The South Florida Water Management District and landowners of the EAA already have an elaborate system to monitor phosphorous leaving farms in the EAA (Germain and Shaw, 1988; South Florida Water Management District, 1992; and Whalen, 1992). This monitoring will be carried out in District Works within the EAA and STA's as well as for water leaving individual farms.

Phosphorous nutrition of crops is a complex issue. Bohn et al. (1985) stated "The chemistry of phosphate in soils has been studied more intensively than that of any other mineral nutrient except nitrogen. Despite the great effort, little definitive can be said about the state of phosphorous in soils: The uncertainties about phosphate chemistry in soils are due to phosphate's strong interaction with many inorganic and organic solid phases, continual uptake by plants and microorganisms, continual return from organic decay, and slow reaction rates." Bohn et al. (1985) were referring generally to aerated mineral agricultural soils. The chemistry of phosphorous is even less understood in aerated organic soils and becomes further complex in inundated organic soils.

Phosphorous has become an even more complex issue as it relates to restoration of the South Florida Ecosystem compared to when we study phosphorous effects only on agriculture. When dealing with the ecosystem, we must not only understand how to most efficiently utilize phosphorous to our advantage agriculturally, but also must devise hydrological systems that reduce the amount of phosphorous that leaves agricultural soils and that tend not to transport phosphorous that has left the soil. Then we need a much clearer understanding of the biological impact of phosphorous on the natural portions of our ecosystem.

As shown in Table 2, up to 605 kg per ha of P_2O_5 has been recommended for agricultural crops in the EAA. The interim goal is to reduce phosphorous in water leaving the EAA to 50 parts per billion. If no further research is done to determine acceptable levels in the Water Conservation Areas, then phosphorous in EAA runoff water will have to be reduced to 10 parts per billion.

Scientists in the EAA began pursuing solutions to the phosphorous issue several years ago. Soil scientists, agricultural engineers, hydrologists, geneticists, plant pathologists, and scientists from other disciplines have helped resolve this issue. Due to the brief but rich history, interdisciplinary, and complex nature of the phosphorous issue, to best deal with it, a meeting of knowledgeable scientists was necessary. Therefore, a workshop at Belle Glade, FL on April 14, 1994 was organized. The goal of the workshop was to outline a comprehensive research plan whose goal was to reduce phosphorous runoff from the EAA to the Water Conservation Areas.

An outline summary of this workshop forms the bulk of this section of the report. Dr. David L. Anderson also supplied a thorough literature review contained in Appendix A. Appendix B is a list of the April 14, 1994 Workshop participants. Also, I requested Dr. F.T. Izuno with the University of Florida, to supply a summary of

Best Management Practices and hydrological issues; and Dr. K.R. Reddy, also with the University of Florida to supply a summary of research needs for Storm Water Treatment Areas. These reports comprise Appendix C.

To begin the task, the workshop participants listed important issues related to phosphorous export from the EAA. After listing them, we discussed as many issues as we had time for, one by one. The suggested output for each issue was to identify and summarize important work completed and ongoing, and to list areas where research or monitoring were needed. The workshop was extremely fruitful as evidenced by the following outline. Due to time constraints, as the day wore on, more time was spent on identifying research needs than on summarizing completed and ongoing work. Readers who can complete this picture are encouraged to do so. Due to time constraints, I was not able to identify citations for all listed statements. In these cases, the name is shown of the person who volunteered the statement.

This workshop was only preliminary attempt to quickly summarize important work already done or ongoing and to identify science needs related to resolving a complex issue. Perhaps the most important recommendation from this section of the report is the need to hold more detailed workshops on several of the issues identified at this workshop. These workshops will often need to be interdisciplinary and include scientists whose major interests are in the EAA, the Water Conservation Areas, or Lake Okeechobee.

APRIL 14, 1994, PHOSPHOROUS WORKSHOP SUMMARY

Issue: Sediments/other particulates.

Completed:

1. Contributes from 50 to 80% of phosphorous transported from EAA canals. (Anderson)

2. Initially quantified particulate phosphorous ratios. Work is also ongoing. Izuno

3. Small-scale effect of drainage rates on phosphorous concentration of canal water. Coale et al. (1994). Izuno et al. (1991) found that fast-drained plots had lower total phosphorous and lower total dissolved phosphorous than slow-drained plots. They were not comfortable with this result. Work is also ongoing.

4. Effect of cleaning sediments from canals and spreading on fields as BMP. Work is also ongoing. Izuno

5. Distribution of total phosphorous in primary canals. Anderson

6. Use of minimum tillage to reduce sediments and therefore phosphorous concentration in canal water. Andreis

7. Chemical treatments to precipitate phosphorous in farm and basin canals. Results showed that it is effective but has high initial and continuous costs. Anderson

8. On-farm ponded water storage maintenance. Promising results. Anderson

9. Soluble ortho-phosphorous accounted for 54-57% of effluent phosphorous for south Florida organic soils (Reddy, 1983).

Ongoing:

1. Characterization of particulates and sediments. Stuck

2. Evaluate efficiency of ditch cleaning as a BMP. Barber may be able to supply citation.

3. How transportable in canals and marshes are various forms of sediments containing phosphorous. Richardson may be able to supply citation.

4. Identify farm characteristics that cause a farm to be a net loader or assimilator.

Proposed:

1. Need to monitor phosphorous levels in farm and South Florida Water Management District canals, dissolved and particulate. Need to determine relative importance of sources of phosphorous in canals: wind, algae, etc.

2. Soil phosphorous chemistry.

3. Origin and composition of sediments.

4. Long- and short-term biological availability of identifiable forms of phosphorous.

5. Chemical precipitation and coagulation for dephosphorization. To include feasibility of application of residues to commercial fields.

6. Use of rock pits and chemicals as sediment traps.

7. Netherlands (Anderson).

8. Determination of erosion index for organic soils.

Issue: Sources of water: rain and Lake Okeechobee.

Completed:

1. More phosphorous enters the EAA in water from rain and Lake Okeechobee than leaves in EAA drainage water. Izuno.

Ongoing:

1. Florida Sugar Cane League has installed 4 new stations to measure rainfall to improve distribution of locations. More needed as described in proposed section.

Proposed:

1. Monitor phosphorous content in canal water as it enters and leaves individual farms.

2. Quantify amount of phosphorous coming into EAA from Lake Okeechobee.

3. Construct water budgets that identify and quantify incoming and outgoing water. Should include surface discharges, seepage (as affected by water depths in Lake Okeechobee and Water

Conservation Areas), ET relationships refined due to water depth and cropping system. To properly build these models, more and better distributed rainfall measurements are needed and should measure both intensity and frequency. These models are needed both EAA wide, and at the individual farm level.

4. Compare dryfall and wetfall phosphorous.

Issue: Subsidence/oxidation/mineralization.

Completed:

1. Total phosphorous liberated from flooded cultivated Histosols was twice that from drained cultivated Histosols. About 6.4 times more phosphorous was liberated with a fluctuating compared to a constant water table from an uncultivated Histosol. Diaz et al. (1993).

2. Sanchez and Porter (1987) reported that from 20 to 150 kg per ha of phosphorous was contained in the soil mineralized annually in the EAA. Reddy (1987) reported 38 to 185 kg phosphorous per ha mineralized annually.

3. No difference in phosphorous exported for a field with low rates of fertilizer and cropped to sugarcane vs. a field with no added fertilizer and left fallow. Apparently amount of phosphorous lost due to subsidence was the major factor for each field. Izuno

4. Reported mass balances for sugarcane, radish, and radish-rice-cabbage systems. Izuno and Coale

5. Calculation of phosphorous in trash and sugarcane sent to mill. Andreis

6. Up to 120 lbs per acre per year released due to subsidence (Sanchez & or Coale?).

7. Total phosphorous content for uncultivated field < sugarcane field < rice field or fallow field < vegetable fields or pasture < horticultural field (Nicholson, 1983).

8. Total phosphorous about 6.7 times higher in Torry than Pahokee or Lauderhill muck. Total phosphorous about equal in cropped or uncropped Pahokee mucks (Diaz et al. 1993).

9. Coale et al. (1993) estimated that a sugarcane crop accumulates about 40 kg phosphorous per ha per year, which ranges from a little more to less than half of the phosphorous mineralized by soil oxidation.

10. Approximately 80-90% of the mineralization of organic matter is due to microbial oxidation (Anderson 1994).

Ongoing:

Proposed:

1. Short-term: Calculation of phosphorous and other nutrient fertilizer recommendations for growing crops at higher water tables.

2. Long-term: Continuous calibration of nutrient recommendations as soil reserves of these elements change after soils are cropped under higher water tables and flooded conditions for several years.

3. Identify mechanisms relating to phosphorous retention and availability.

4. Partition phosphorous sources and uses. Phosphorous may have different characteristics depending upon its source and use. This could lead to new soil classification maps.

Issue: Flooding and phosphorous.

Completed:

1. Flooding increases phosphorous concentration in drainage water by about 4-8 times compared to drained conditions (Reddy, K.R., 1983) and increases phosphorous availability (Reddy, 1987).

2. Water between soil pores has 10 to 15 times more phosphorous than flood water (Anderson).

3. Phosphorous concentration in soil decreases with soil depth (Izuno).

4. In the short term, flooding will result in drainage water with higher phosphorous concentrations. With long term flooding, it is likely that phosphorous content of drainage waters would decline. (Sanchez and Porter, 1987).

5. Rate of soluble phosphorous production in soil under anaerobic conditions was 0.016 g phosphorous per m^2 per day. Flux of phosphorous as a result of diffusion was about 0.0098 gm phosphorous per m^2 per day. (Reddy and Rao, 1983.

6. Losses of phosphorous due to mineralization of organic phosphorous, adsorption-desorption of phosphorous, and diffusion of underlying sediment to the overlying water accounted for 53% of the solubilized phosphorous.

7. The three most important physiochemical properties affected by flooding are pH, oxidation-reduction potential or redox potential, and ionic strength or salt concentration. Data on pH of flooded organic soils is not available. Redox potential is a measure of electron availability. Well drained organic soils have redox potentials > 300 mV and this drops to as low as -350 mV in flooded organic soils. Flooding organic soils causes an increase in the amount of ions present in soil solution. (Reddy, 1987.)

8. Flooded fallow fields yielded extremely high phosphorous concentrations during draindown (Izuno et al. 1991b).

9. Since rice is a harvested commodity, it results in an export of phosphorous from the EAA (Izuno et al. 1991b).

Ongoing:

1. Especially as related to rice production, water management effects on phosphorous concentration of drainage water (Izuno).

Proposed:

1. Basic understanding of phosphorous cycling. Phosphorous retention and availability as related to phosphorous and soil properties.

2. Understanding of effects of percolation on phosphorous.

3. Determination of stages of growth of when and for what duration sugarcane can withstand flooding so that water high in phosphorous can be flooded on sugarcane fields before being pumped off farm.

4. Determination of differences among sugarcane cultivars' responses to flood water high in phosphorous.

5. Determination of effectiveness of the BMP of flooding sugarcane with water high in phosphorous concentration.

6. Determination of hydraulic designs necessary to move and store water among fields. This is necessary both at the farm and EAA levels.

7. Research to minimize impact of flooding on planting and harvesting crops.

    a. Harvesting rice under flooded conditions.
    b. Water management strategies to drain flooded fields for harvest or planting.
    c. Use of air seeding for rice to plant under flooded conditions.

8. Determination of ET's for various crops under different flooding cycles and determination of effect of changing ET on phosphorous export.

9. Design, use, and feasibility of on-farm water retention and storage both for farm and Water Conservation Area water needs.

10. Comparison of surface water storage and storage in 50-60' deep aquifers.

Issue: Wind erosion.

Proposed:

1. Determination of relative importance of sources of wind erosion to total phosphorous load. Some sources are dust from cultivating soil and dust from roads.

2. Quantification of effect of water table depth on wind erosion.

3. Quantification of effects of minimum tillage on wind erosion.

4. Use of wind breaks.

Issue: Hydraulic control.

Completed:

1. Prediction of phosphorous discharge from fields with different pumping rates (Bottcher).

2. Model that describes field drainage and phosphorous transport. Model includes crops, fertility, porosity, soil moisture, seepage, spatial distribution, ET crop coefficients, and weather data. This is a full water budget. This has been done at the field scale. A project is now underway at the farm scale (Izuno).

3. "For reservoir soil, about 70 and 76% of the floodwater P was removed under aerobic and anaerobic water column conditions, respectively. For flooded organic soil, 51% of the aerobic floodwater P was removed after 2 days of incubation, followed by an increase in soluble P concentration of the overlying water, whereas about 64% of the anaerobic floodwater P was removed during a 29-day incubation." (Reddy and Graetz, 1981).

4. Use of biological filters. Reddy et al. (1982) reported on the use of water hyacinths, elodea, and cattails in reservoirs to filter phosphorous and nitrogen.

5. EAA phosphorous loading varied from 0.1 to 2.9 kg per ha per year (Izuno et al. 1993)

Ongoing:

1. Development of sets of site-specific dynamic on-farm models to predict phosphorous concentrations. Model to include such factors as: hydrology and chemistry of canals and drainage ditches, drainage rates and duration, and solubility of sources of phosphorous (Stuck).

2. Phosphorous-loading profiles, for particulate and dissolved phosphorous, as functions of pumping duration and speed.

Proposed:

1. Basin wide, the South Florida Water Management District and farmers need to determine ways to better coordinate their pumping.

2. Effect of cropping shallow soils on hydraulic practices necessary to reduce phosphorous export.

Issue: Phosphorous in canals.

Completed:

1. Ten-year data that quantifies phosphorous levels in various canals and expected canal loadings.

2. Use of aquatic vegetation in canals to harvest and spread on fields (Reddy) SFWMD report?.

3. EAA baseline phosphorous concentrations at 0.06 mg per liter to 0.62 mg per liter (Izuno et al. 1993)

4. Main-farm and District canals had lower phosphorous concentrations than those found in farm fields (Izuno et al. 1991a).

Ongoing:

1. Impact of vertical canal profiles on phosphorous removal (Stuck).

Proposed:

1. Measure interflow between South Florida Water Management District main canals and farm canals. One major issue within this topic is to determine the effects of one farmer's exported water to the main canals on other farmers' imported water from the main canals.

2. Effects of phosphorous content in canals on phosphorous release and control of oxygen content in canals.

3. Effects of nutrient recycling of vegetation.

Issue: Storm water treatment areas (STA'S).

Participants at the workshop recognized that the South Florida Water Management District is in the process of planning and carrying out research to determine how to best utilize STA's to remove or filter out phosphorous before it arrives to Water Conservation Areas. The STA's will eventually be owned by the State of Florida, and probably their use will incur a cost to the State. Therefore, low-profit or negative-profit agricultural systems may be the most efficient and least costly means of utilizing STA's. An advantage of an agricultural approach in these areas is that some phosphorous would be physically exported from the ecosystem in the harvested biomass of the crop. Some wetland agricultural systems that were mentioned were forage crops, tree crops (fast growing cypress), and a rice-crawfish system.

Issue: Fertilizers.

Completed:

1. Up to a 50% reduction in phosphorous fertilizer on lettuce was achieved by applying fertilizer in a band rather than broadcasting it. (Sanchez).

2. Soils with higher pH's tend to tie up phosphorous more than soils with low pH's (Anderson). Phosphorous deficiency is associated with low pH organic soils (Anderson, 1989).

3. Use of vesicular-arbuscular mycorrhizae to enhance phosphorous utilization by celery. Plants infected with mycorrhizae in a greenhouse study contained 56% more tissue phosphorous than those not infected (Datnoff et al. 1992).

4. Identification of a sweet corn variety that uses phosphorous more efficiently than others (El-Hout).

5. EAA growers already remove 179% of their phosphorous fertilizer and 201% of their potassium fertilizer. Phosphorous export from sugarcane fields has been reduced to 0.37 kg per ha per year (Izuno).

6. Phosphorous fertilization plus fertilizer phosphorous greatly exceeds phosphorous requirements of some crops. (FSCL, 1978 in Porter et al., 1991)

7. The maximum phosphorous fertilizer recommendation for sugarcane on soils requiring high phosphorous fertilizer is less than half of the rate of soil phosphorous mineralization. Coale et al. (1994a)

8. Phosphorous fertilizer applied to sugarcane did not affect drainage water phosphorous levels Coale et al. (1994b).

9. Phosphorous fertilizer recommendations for Florida sugarcane range from 0 to 37 kg phosphorous per ha for the plant crop, 0 to 35 kg per ha for first-ratoon crops and average 20 kg per ha for second-ratoon crops (Anderson, 1989).

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ACKNOWLEDGMENTS

I received help from many sources in preparing this manuscript and wish to express my appreciation. In fact, the task was endless and too multidisciplinary for one author. I regret if I missed important citations in this document, but I hope that the summary and organization process will continue. One way to insure that it does continue would be for scientists to send summaries of their important work to the Science-Sub Group. Some of the persons who offered assistance in preparing this document were D.L. Anderson, H. J. Andreis, E. Arias, J.A. Browder, G.R. Burns, C.E. Carter, R.H. Cherry, F.J. Coale, J.C. Comstock, C.W. Deren, J.W. Dunckelman, B.R. Eiland, Nael El-Hout, E. Flaig, G.J. Gascho, D.G. Hall, F.T. Izuno, D.B Jones, J.D. Miller, R. Perdomo, P.S. Porter, K.R. Reddy, P. Rosendahl, C.A. Sanchez, T.J. Schueneman, J.M. Shine, Jr., G.H. Snyder, O. Sosa, Jr., D. Swift, P.Y.P. Tai, M.F. Ulloa, D. Unsell, P. Whalen, and all participants of the April 14, 1994 workshop.

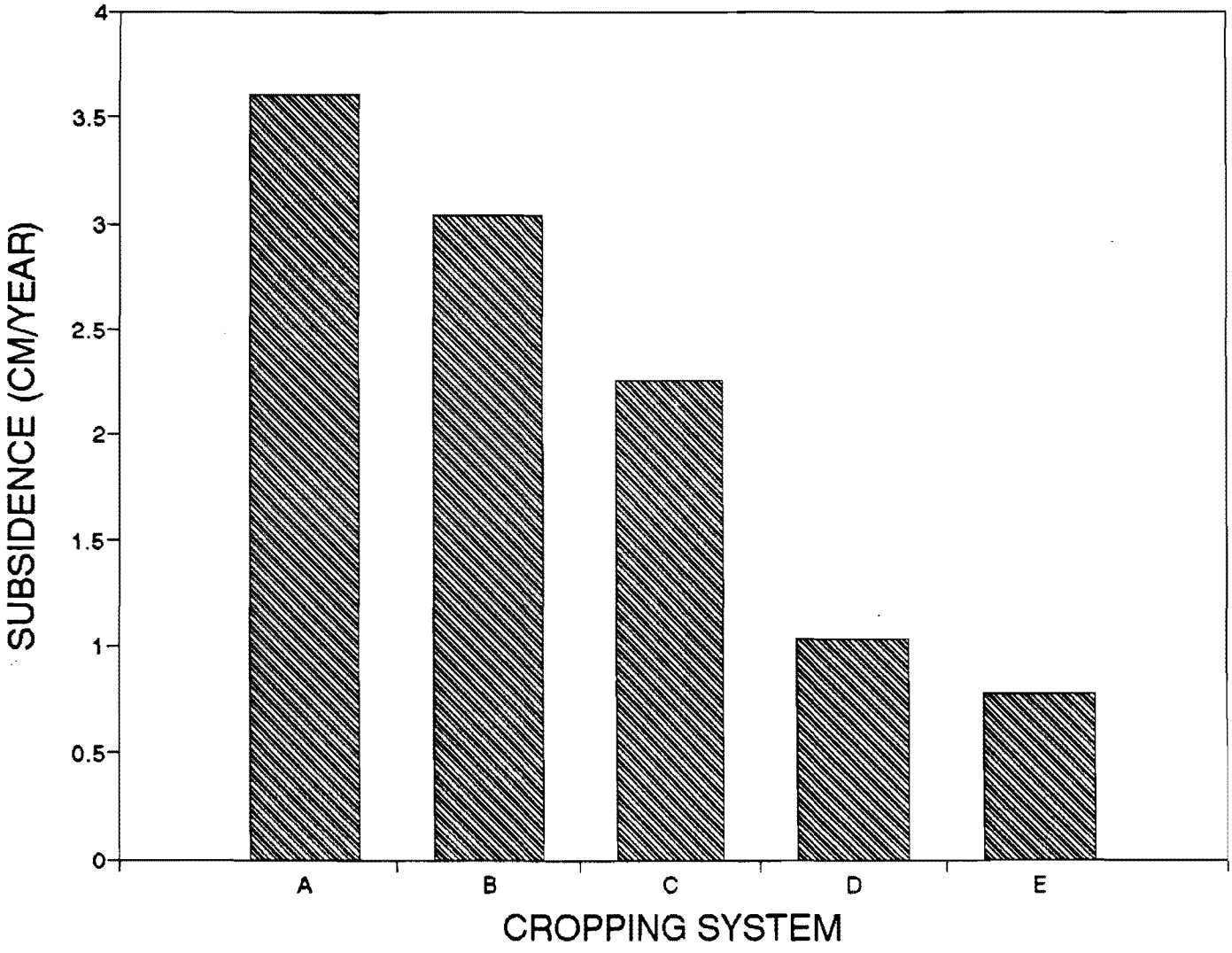


Figure 1. This figure presents theoretical subsidence scenarios in the EAA using the equation of Stephens et al. (1984). A: All cultivated soils in EAA at 60 cm water table. B: Same as A except 23,000 ha of winter vegetables summer flooded and 8,815 ha rice summer flooded. C: Same as B except additional 37,000 ha sugarcane available for summer flood. D: Same as C except nonflooded EAA at 30 cm water table. E: Same as D except assumes sugarcane causes 25% reduction in subsidence compared to other crops.

Appendix A

I requested Dr. David L. Anderson to prepare a literature review for seven subject categories related to phosphorous issues in the EAA. He submitted the following thorough review.

Soil Sediment Characterization in the Everglades Agricultural Area: Relevant Literature.

Categories:
(1) EAA Water Quality
(2) Lake Okeechobee Water Quality
(3) EAA Sediments
(4) Lake Okeechobee Sediments
(5) Soils
(6) Plans, Implementations, Measurements
(7) Dutch Sediments

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Appendix B

List of Attendees at April 14, 1994, Workshop

David L.	Anderson	University of Florida EREC
Henry	Andreis	United States Sugar Corp.
Velton	Banks	Florida Sugar Cane League, Inc.
Del	Bottcher	Soil & Water Eng. Tech.
Joan	Browder	U.S. Dept. of Commerce-NOAA/Fisheries
Gary	Buckingham	USDA-ARS, Gainesville
George R.	Burns	USDA-ARS, Athens, GA
Laurene	Capone	University of Florida EREC
Lawrence	Datnoff	University of Florida EREC
C.W.	Deren	University of Florida EREC
Barney	Eiland	Okeelanta
Nael	El-Hout	South Bay Growers, Inc.
Barry	Glaz	USDA-ARS, Canal Point
Forrest T.	Izuno	University of Florida EREC
Gaspar	Korndorfer	University of Florida EREC
Ken	Liudahl	USDA-SCS-WPB
J.D.	Miller	USDA-ARS, Canal Point
Russell	Nagata	University of Florida EREC
Bill	Orem	U.S. Geological Survey
Ramesh	Reddy	University of Florida, Gainesville
Ron	Rice	University of Florida EREC
Fernando	Sanchez	Sugar Farms Co-op
Lewis	Schoolfield	Florida Sugar Cane League, Inc.
Jim	Shine	Florida Sugar Cane League, Inc.
George H.	Snyder	University of Florida EREC
James D.	Stuck	University of Florida, Gainesville
Modesto F.	Ulloa	Sugar Farms Co-op
Henro	Van Dohkum	University of Florida EREC
Cees Jan	Vermulst	University of Florida EREC

Appendix C

Hydraulic and Best Management Practice Research Needs in the EAA

Forrest T. Izuno
Everglades Research and Education Center
University of Florida

Research objectives related to hydraulics and Best Management Practices (BMPs) in the EAA are interrelated. Research scopes overlap and are applicable to the field, farm, and basin levels. The primary goal of such research must be to protect the environment while maintaining agricultural production at the current levels of quantity and quality. An equally important consideration is to ensure adequate water supply to meet the growing urban demand for potable water in south Florida. Research in the past has been rushed, scientifically incomplete, sporadic, and not part of a comprehensive plan to fairly serve agricultural, environmental, and urban interests. While numerous studies have been conducted relative to water quality and quantity, there are still many questions which must be answered in the interest of achieving sustainable agriculture given the ever increasing direct competition with environmental and urban demands.

One of the first issues that must be resolved is whether it is appropriate to view farm discharge water and P as absolute contributions to the basin. The concepts of net P loading and net water user or supplier have been discussed, but never resolved. A large number of sugarcane farms in the EAA are net assimilators of P where more water enters the farms in irrigation or rainfall than leaves in drainage water. This assessment does not even account for the P mineralized during soil oxidation or P exported in the crops. It is a simple but powerful realization that many farms are simply not contributing P to the basin. In fact, those farms actually filter P from rain and irrigation sources. Farm characteristics that lead to farms being net loaders or net assimilators need to be identified and applied across the EAA to allow researchers to focus attention in areas where the most P loading reduction is necessary. Obviously, one must look at the P concentrations as well as the volumes of water pumped to fully understand the process. For example, large volumes of water may enter the farm in relatively low concentrations while smaller volumes leave during drainage pumping at substantially higher concentrations. This leads directly to the question of which is more harmful to the environment; constant discharges of water with lower P concentrations or sporadic slug discharges of high P concentrations.

Another major question that requires resolution is what forms of P are actually detrimental to the environment. The current assumption is that total-P discharges lead to detrimental downstream environmental effects. Yet, it is generally accepted that some of the P attached to particulate matter is not readily available for plant uptake and can only be extracted by acid digestions. If this particulate P is in fact immobile then it may have no effect on the environment. The proportions of particulate and soluble P in the total-P entering and leaving the farms need to be determined. This determination will aid in the development of BMPs to control the P which is most detrimental to the south Florida water system. It will also help to determine what types of BMPs would be most effective in reducing total-P discharges. Currently, only a small database of this type exists.

In line with the above, the origins of the sediments or particulate P need to be determined. Researchers need to determine whether particulate P in discharge water comes from scouring of the channel bottom during drainage, detritus, or from field surface erosion driven by surface runoff or wind. In addition, the comparative effects of draining a farm block over the field surface or through the soil profile and/or rock layer must be determined. The results will lead to a more productive and focused BMP implementation effort.

Canal and ditch cleaning has been discussed as a BMP for reducing P loads leaving farms and increasing farm water storage capacities. It is, however, known that cleaning ditches stirs up sediment and

breaks down the structure of the channel banks. To gain the benefits of ditch and canal cleaning without incurring the adverse effects associated with the activity revolves around timing and frequency.

Water can be held back on farms to a certain degree, dependent on the crops grown and time of year. Data need to be generated that specifically indicate when fields can be kept wetter than current practice and for how long without adverse crop effects. To keep water on farms, some growers are resorting to a moving flood system where water is moved from block to block around the farm. Currently this is being done on a trial and error basis. Research needs to be done to determine the extent to which such activities can be done without adverse crop effects. Additionally, it has been advised that no water from flooded fields should leave a farm directly. Rather, the water should be moved around the farm internally allowing the crops and soils to assimilate and adsorb P. This activity will affect soil fertility and crop production in the short and long terms. To what extent is unknown.

Soil oxidation is a major source of P in the EAA. Biological oxidation must be reduced to limit the amount of P available for leaching. Yet, the mineralized P also adds to the fertility pool from which crops may draw during growth. This change in P mineralization will change the fertilizer requirements for the crops. Potentially, reduced P mineralization could lead to increased fertilization requirements thus negating all pollution related benefits of reducing P mineralization. Attached to soil oxidation under the category of soil subsidence is surface water runoff and wind erosion of the soils. The amount of soil that leaves a field in these ways on an annual basis needs to be determined. Much of the eroded soils may end up in the drainage stream, adding to the P load.

Soil depths throughout the EAA have decreased dramatically since the area was canalized. Currently, growers are attempting to drain the same parcels using the same pump and ditch management schemes that have been in place for years. Ditch spacings and pumping capacities generally remain the same. Physical systems may have to more efficiently manage water on the farmland. More efficient water management could lead to reduced P loading, reduced soil subsidence, and better crops. The costs, benefits, and designs of improved water management systems must be researched.

Finally, when all is done at the farm level, it may be discovered that the farms themselves can serve as effective P filters. This may obviate the need for Storm Water Treatment Areas (STAs) at the magnitude currently being proposed. It must be understood, however, that in spite of sizable P loading reductions achieved at the farm outlets, the basin level load reduction may not be evident to the same extent at the South Florida Water Management District pump stations unless the management of the area canals is also improved. In fact, growers may not be able to fully implement P reduction BMPs unless the management of the receiving canals is changed to accommodate new irrigation and drainage water volume and timing requirements. Growers and basin water managers must develop integrated and complementary water management schemes to achieve the full benefits of the P reduction BMPs.

Evaluation of Critical Issues Related to Nutrient Retention in the Everglades Watershed

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The Everglades Agricultural Area (EAA) comprises of 607,692 acres with peat depths ranging from < 1 foot to 10 feet deep. Because of drained conditions of EAA, these soils are biologically oxidized at a rate of approximately 1 inch per year. Soils of this area are classified based on soil peat depth. Results of soil subsidence study (US-SCS, 1988) suggest that approximately 81% of 607,692 acres of EAA typically have a soil depth of <51 inches. By the year 2000, it is estimated that about 87% of the EAA soils will have peat depths of <36 inches, while about 45% of the soils will have peat depths of < 12 inches. Further extrapolation of these results (assuming 1 inch subsidence per year) suggests that by the year 2050 approximately 96% of the EAA will have peat depths < 12 inches. It should be noted that soil subsidence rates can decrease as the soil depth decreases, as a result of increased mineral matter and bulk density. At this time, information is not available on the rate of biological oxidation as a function of peat depth and associated increase in mineral matter and bulk density. At this time, it is difficult to predict the effect of soil loss on farming practices in the EAA. Apparently, sugarcane is currently being cultivated even on soils with peat depth of about 12 inches. However, soil loss can have significant impact on water management and water quality.

Soil loss as result of biological oxidation or natural fire will result in enrichment of phosphorus in the soil profile. As the organic matter is oxidized, organic phosphorus (which represents up to 80% of the total P) is converted into inorganic P. Depending on soil conditions and physico-chemical properties of the soils, inorganic P can be potentially leached during draining and flooding cycles. Soils with deep peat depths will have greater capacity to store soil moisture in the soil profile during the rainy season than shallow organic soils. In order to maintain optimal field moisture conditions, shallow organic soils need to be drained more frequently than soils with deep peat depths, thus resulting in the release of more nutrients. For example, in Lake Apopka Basin we have measured high P losses during drainage of shallow organic soils (105 kg P/ha year) than deep organic soils (34-72 kg P/ha year). However, under certain soil conditions, phosphorus retention capacity of organic soils can be increased as result of soil subsidence, primarily due to increased mineral matter and bulk density. At this time we do not have any experimental evidence to show that phosphorus retention capacity can increase with soil subsidence.

Soil subsidence can be significantly reduced by maintaining high water-table conditions and by creating partial anaerobic conditions in the soil. If the farming practices continue at current level, soil subsidence can result in more severe drainage water quality problems in the EAA during the next 50 years. However, this prediction is based on the assumption that soil subsidence will increase the phosphorus release into drainage water and frequency of drainage will be higher on shallow organic soils than deep organic soils.

Several questions need to be addressed before evaluating whether Stormwater Treatment Areas (STAs) are needed if 60 years from now 96% of the land area in the EAA has peat depths of less than 12 inches.

1. Will the land area under production agriculture decrease with time as the peat depth decreases due to soil subsidence?

2. What effect soil subsidence and shallow peat depths will have on water management and drainage water quality?

3. What type of crops will be grown on shallow organic soils, if the soils are not suitable for sugarcane production?

4. Will the phosphorus retention capacity of the soils increase with soil subsidence?

5. Will the land areas (shallow peat depths) not suitable for production agriculture be restored as wetlands?

There are several unknowns with regard to future of the EAA especially in the management and farming practices. At least during the next 50-60 years STAs will be necessary to abate the pollution from the EAA drainage water and protect the Everglades Protection Areas.

Issues Related to Stormwater Treatment Areas:

Freshwater wetlands, swamps and marshes, and flooded soil systems have been used as a possible means of reducing N and P levels of wastewaters. To maximize the N and P removal rate as well as the net storage capacity of the wetlands, it is important to understand the biogeochemical processes responsible for nutrient removal. Wetland soil chemistry is very complex because of the interactions between organic and inorganic forms of nutrients and associated chemical and biological components. The degree of soil reduction in wetlands will have a significant impact on labile and non-labile pools of C, N and P, and ultimately their retention/release by these soils. These mechanisms need to be quantified for STA sites. Although N and C processes are important, emphasis is usually placed on P because in many systems P effluent quality dictates the design criteria for constructing nutrient removal systems.

Phosphorus removal in wetlands primarily occurs through physical, chemical, and biological processes functioning in the soil-water column. A significant portion of floodwater and porewater N and P can also be removed through uptake by macrophytes and algae. Rate of N and P removal by these processes is influenced by the physico-chemical conditions that exist in the overlying water and in the underlying soil. Some of these conditions are: (1) dissolved O_2 in the water; (2) pH; (3) temperature; (4) residence time of water; (5) water depth; (6) mixing in the water column; and (7) presence of aquatic macrophytes and algae. Although the soil processes are important in controlling efficiency of a constructed marsh, the reactions occurring at the root-soil interface also play a significant role in C, N and P dynamics of a wetland. For example, oxygen transport capacity of wetland plants can play a significant role in decomposition of organic matter and N losses as a result of nitrification-denitrification reactions. The oxidized rhizosphere can also have a significant effect on P solubility in the root zone.

The soils at proposed STA sites are classified as Histosols and have been used for crop production (sugar cane, vegetables) for the last four decades. Conversion of these areas into a marsh will alter the physico-chemical properties of the soils, thus having a significant impact on the nutrient assimilatory capacity of the created marsh. Thus, a basic understanding of biogeochemical processes regulating P behavior in organic soils is necessary to determine the functioning of these constructed marshes.

Several critical issues need to be addressed immediately for successful establishment of constructed marsh for nutrient retention. Some of these issues related to soil processes are:

- How much P can be retained by STA soils and how long?
- How long will the initial soil nutrient release sustain upon creation of a marsh?
- How stable and permanent are the P compounds stored in the system? and

- Short-term soil processes vs. long-term soil processes...which one controls water quality?

The success of the STA marsh depends on the management of water flow, which will require a thorough understanding of the hydrodynamic processes in the system. Both surface flow and sub-surface flow play a major role in nutrient retention. Thus, an accurate water budget is needed for evaluating the effectiveness of the STA marsh. It is likely that percolation rates in these soils can be high and if the water flowing through the profile is forced through the underlying limestone, effective P removal can be achieved.

Full-Scale STA Operation:

The success of full-scale STA depends on the management of hydrology. Vegetation only provides short-term storage, thus the cycling of nutrients during decay of detrital material dictates long-term storage. Cycling of these nutrients between live and detrital components of the marsh needs further evaluation. In a full-scale STA operation, management of soils and vegetation may be an expensive task, thus operation should focus on hydrology management. The current design of full-scale STA does not provide a mechanism to regulate effluent quality, instead it relies primarily on natural ecosystem processes. This does not guarantee the low discharge P limit required to be met by STA. The full-scale STA should consider a final filter with limestone or limestone berm to reduce P concentration to the lowest levels possible. Critical research issues for full-scale STA's are:

(1) Determine hydrologic flow path in the system for optimal HRT and nutrient retention.

(2) Spatial and temporal nutrient exchanges between soil-water-plant components.

(3) Movement of water through underlying limestone layer and impact on water quality.

(4) Evaluation of final limestone filter for effective P removal.

(5) Water and nutrient budgets.

(6) Determine long-term effectiveness of the system under extreme hydrologic conditions (drought vs. high rainfall conditions).

Experimental Cells:

The experimental cells currently available provide an excellent opportunity to evaluate various management scenarios, and for possible implementation of successful techniques in full-scale STA operation. These cells should be evaluated to study the interaction between hydrology, vegetation and soil components.

(1) Evaluate hydraulic and nutrient loading on effluent quality.

(2) Wet/dry cycles and impacts on nutrient release or retention.

(3) Soil amendments to bind native and added P.

(4) Role of vegetation on nutrient storage and release.

(5) Identify key biogeochemical processes regulating water quality and measure rates for inclusion in model.

(6) Develop a model to evaluate the system's performance and identify critical processes.

(7) Develop water and nutrient budgets.

Process Level Research—Laboratory and In-situ Conditions:

Since the success of the marsh is evaluated based on the effluent P concentration, it is critical to conduct research related to the biogeochemical processes of P in these soils. Because the large proportion of P is bound in organic form, P release is directly related to organic matter decomposition. The STA marsh receives significant levels of SO_4^{2-}, thus SO_4^{2-} respiration can play a significant role in the breakdown of organic matter. Similarly, fluctuations in hydrology can stimulate microbial breakdown of organic matter and release of P. To develop a complete understanding of the role of these soils, we need the following additional information on nutrient dynamics in the system.

- Characterization of organic forms of nutrients and their relative biodegradability. Determine the bioavailability of P forms in the influent and effluent water.
- Influence of aerobic, facultative anaerobic and obligate anaerobic respiration on decomposition of soil organic matter and release of nutrients. Establish the role of NO_3^- and SO_4^{2-} loading on breakdown of soil organic matter and release of P.
- Phosphorus retention capacity of organic soils, as influenced by soil pH and redox conditions. Stability of various phosphatic compounds under these conditions.
- Determine the mechanisms of P retention by organic soils, and develop ways to increase P retention.
- Phosphorus exchange between soil and the overlying floodwater as influenced by nutrient loading to the marsh. Establish the role of benthic activity, macrophytes and periphyton communities on P exchange rates.
- Determine the spatial and temporal effects on nutrient exchange between soils and the overlying water column.
- Determine the role of floodwater physico-chemical properties on P solubility.
- Determine the interaction between detrital accumulation and decomposition and soil processes.
- Soil – P leaching studies – determine potential P leaching during downward flow through soil.
- Determine P retention by limestone during downward flow of water.
- Determine the effect of flooding duration – water-table depth fluctuation on P release/retention.
- Effects of draw-down and drying to reduce 'floc' layer in cattail area.
- Develop an internal nutrient budget for the marsh.
- Develop a mechanistic soil process model to synthesize experimental data and integrate into management models to optimize the functioning of the marsh.

SUBREGION 5:

EVERGLADES WATER CONSERVATION AREAS

BACKGROUND

The Water Conservation Areas (WCA's), comprising some 3,554 square kilometers (1,350 square miles), represent an area equivalent to approximately one-third of the original Everglades landscape. These areas consist of five interconnected diked impoundments encompassing that portion of the remaining natural Everglades system situated on the topographic gradient of the Everglades Watershed downslope (or south) of Lake Okeechobee and immediately upslope (or north) of the Everglades National Park. The area is wedged between the developed Atlantic Coastal Ridge (east coast) on the east and the Everglades Agricultural Area (EAA) and the Big Cypress National Preserve on the north and west. These impoundments were constructed in phased steps over a number of years, culminating in the current configuration in the early 1960's. The principal function of the units is water control for economic development. The system provides a compartmentalized detention reservoir for excess water from the EAA and parts of the east coast region as well as accommodating flood discharges form Lake Okeechobee. The levee system on the east prevent flood waters from inundating the principally urban east coast while providing water supply for the east coast agricultural lands and the Everglades National Park. The areas further enhance the supply to the east coast by serving to recharge the Biscayne Aquifer, the primary drinking water source for the southern urban east coast while retarding salt water intrusion. All these functions are to be accomplished in a manner benefitting the considerable wildlife resources dependant on the system.

The WCA's are formed by earthen dikes and peripheral canals connected to the major drainage canal conveyance system traversing the EAA and the east coast ridge. The WCA's have a combined storage capacity of 1,882,000 acre-ft through which the various functions of water storage, water supply, and flood control are accomplished. The three units are aligned north to south and connected serially with discharges from the upslope unit representing input to the unit immediately downslope. All receive direct inputs from rainfall, with the lower two units (WCA 2 and WCA 3) receiving additional inputs from the Miami and North New River Canals. The latter two units are further subdivided to conserve surface water from excessive entrainment into the Biscayne Aquifer.

The pre-drainage landscapes of the WCA'S consisted of complex mosaics of vegetative habitats interspersed variously on the low-relief, low-gradient peat bed that accumulated over the past 5000 yrs. These vegetative habitats were products of the interaction of the plant communities and the natural forces of hydrology (both flow and hydroperiod) and fire, the same forces responsible for the ontogeny of the peat. The resultant was a enormously immense and heterogenous complex of aquatic and vegetative structures. Today, the complex mosaics of tree islands, sawgrass strands, wet prairies, and aquatic sloughs represent the natural remnants of this once vast complex.

The WCA's are critically important to the wildlife resources of the Everglades. The areas are rich in fish and wildlife, particularly wading birds (including the Endangered wood stork), the American alligator, and the Endangered snail kite. Grass shrimp, crayfish, and select fish species are well adapted to the periodic wet/dry regimens that characterize the Everglades

ISSUES

The WCA's are precariously juxtaposed to the urban development on the east and agricultural development to the north and west, concomitant with their ever increasing demands for flood protection and consumptive needs for water supply. By virtue of their spatial placement in the center of the hydrologic gradient; the highly managed nature of their input and output regimens; and the documented consequence of receiving the nutrient enriched

drainage of the surrounding agricultural and urban areas (SFWMD Everglades SWIM Plan), these areas are severely impacted by the current water management operations of the Central and South Florida Project and are integral to the restoration effort. These areas contain the last remnants of the tall-sawgrass landscape, as well as, the bulk of deep marshes, wet prairies, and tree island hammocks outside the ENP (Light and Dineen, 1994). Additionally the WCA's provide habitat for a diverse array of flora and faunae, including endangered species, particularly snail kites and wood storks. Since a major portion of the Kissimmee/Okeechobee and East Coast Ridge drainage are diverted to sea for regulatory flood control, the historic hydrologic throughput or volume through these units is severely reduced. The areas have been virtually isolated from the Kissimmee/Okeechobee watershed and the resultant sheet flow with all its natural variation that was a critical element in the formation and the ecological structure and function of the Everglades landscape. The impoundments instead serve to replace the historic inclined hydrologic gradient, formerly subject to overflow, with a series of stepped basins connected through control structures that localize and minimize the forces of the flow that historically shaped and maintained the landscape structure of the system. In addition, by virtue of their hydrologic regulation schedules, these systems are practically decoupled from rainfall, becoming over inundated in response to flood protection and overly de-watered in response to consumptive water supply demands in dry years. In addition there have been major altered hydroperiod impacts resulting from the impoundment of these systems. Channelization coupled with impoundment has increased depth and hydroperiods at the southern end of the systems, while over de-watering and shortening hydroperiods in the northern ends. One resultant of the above combined modifications is the areas are extensively invaded by the exotic Melaleuca as well as numerous exotic fish. Another is the shortening of the requisite water level conditions in time and space, vital to successful wading bird reproduction (Frederick and Collopy, 1989). The latter is particularly critical since these units provide major rookery and foraging habitat for wading birds in normal and dry years.

Excessive nutrient loading (particularly phosphorus) resulting from the introduction agricultural drainage into the system has severely altered the ecological structure and function of vast areas within the WCA's (approximately 6000 acres in WCA 1 and 25,000 acres in WCA 2). In its natural state the Everglades ecosystem was essentially an oligotrophic system, deriving most of its nutrient input through atmospheric deposition. Concomitant with the drainage and development of the EAA, the WCA's have become retention/detention systems for storage and elimination of agricultural drainage. The chronic introduction drainage waters with elevated concentrations of nutrients (10 to 20 times background concentrations) has resulted in massive conversions of sawgrass and wet prairie communities to stands of robust Typha and Typha/saw grass mixes along with a replacement of the typical periphyton mat communities to species mixes more reflective of deteriorated water quality.

In addition to the Federal Task Force for the Restoration of the South Florida Ecosystem and the Central and South Florida Project of the U.S. Army Corps of Engineers, there are three other major initiatives, mandated by the State of Florida, intended to intended to address the deterioration of the Everglades system and provide measures for restoration. These are the Everglades Surface Water Improvement and Management (SWIM) Plan under Sections 373.451-373.4595, F.S.; the Marjorie Stoneman Douglas Act and; the provisions of the 1994 Everglades Forever Act. All provide for an extensive restoration plan to improve water quality, water quantity, and hydroperiods in the Everglades. All establish an extensive research an monitoring program to evaluate the hydrological needs of the Everglades and to develop technology and BMP's designed to improve water quality. In response to these mandates the South Florida Water Management District has developed a comprehensive research plan entitled The Everglades Research Plan (ERP) that attempts to describe research efforts deemed necessary to fulfill the legislative and judicial mandates for reduction of pollutant loads to the Everglades (principally phosphorus) over the next several years. The goal is twofold: 1) reduction of nutrient loads to acceptable levels (short-term), and 2) regulating nutrient sources system wide to restore the physical ,chemical, and biological integrity of the Everglades system. These goals closely parallel many of the objectives stated below, excerpted from the Science Sub-Group Report.

The following section is the result of a process employing the Adaptive Environmental Assessment Approach for identifying major issues and information needs. The process began with stating the intended objectives of the restoration project (both hydrological and ecological) followed by and to frame strategic questions that address

the information needs required to meet the objectives. This assessment was conducted in a two day workshop format with invited participants with the necessary expertise to address the multidisciplinary issues and scientific/technological approaches to resolving the issues. Scientists involved in the development of the SFWMD ERP were full participants in the process and were instrumental in helping to assure the approach outlined below was complementary to the efforts outlined in the ERP. The Executive Summary of the Everglades Research Plan is appended (Appendix 1). It is important to note that while the plan outlined below encompasses several similar research initiatives, the hydrologic and ecologic objectives driving the ERP assume the continuance of the present configuration of water control structures to be modified only slightly to accommodate hydrologic changes, principally in the form of modifications to current water regulation schedules (principally manipulating hydroperiods), and operated within the context current and projected demands for supply and flood protection. The objectives set forth in the Science Sub-Group Report (outlined below) are principally targeted to hydrological and ecological restoration of the system, including impairment resulting from the present configuration of the water control structures, as well as, regulation schedules.

HYDROLOGICAL RESTORATION OBJECTIVES

- Restore predrainage hydrologic gradients, hydropatterns, sheetflow and timing, as defined by output from the Natural Systems Model.
- Decompartmentalize the Water Conservation Areas.
- Reestablish the modern historic natural rainfall-driven pattern of water discharge and timing between WCA3A and Big Cypress, as defined by output from the Natural Systems Model.
- Reestablish sheetflow from the EAA into the Water Conservation Areas.
- Reestablish the modern historic hydrologic link between WCA3A and WCA3B as defined by output from the Natural Systems Model.
- Provide delivery water to Everglades National Park that is in compliance with the Park's Outstanding Florida Water designation, Class III water quality standards, and is in compliance with the terms of the 1991 Settlement Agreement and the 1992 Court Order.
- Deliver water from the EAA into the Water Conservation Areas that complies with Class III water quality standards and is of sufficient quality for preventing an imbalance of native flora and fauna and maintaining ecological integrity.
- Water delivered to Loxahatchee National Wildlife Refuge and other WCAs is in compliance with the Refuge's Outstanding Florida Water designation and is in compliance with the terms of the 1991 Settlement Agreement and the 1992 Court Order.

Research Question 1: What were the predrainage sheet flow and hydro-patterns (flow rate, volume, timing, water budget, spatial extent) over the range of rainfall/evapotranspiration conditions that occurred within annual to century time scales?

Approach:

- Develop a series of spatially explicit grid-based hydrologic models (natural systems type) at various spatial/temporal scales to hindcast predrainage hydro-patterns at scales that match critical system features (topographic gradients, waterway networks, flow ways, etc.) and processes (rainfall extremes, overflow

events, stage fluctuations, etc.) The models should be modified hierarchical versions of the current natural systems models of the SFWMD's SWMM model. A specific protocol should be developed to evaluate appropriateness of scales, both temporal and spatial to address the above question.

- Synthesize existing information on basement topography, historic topographic elevations, rainfall/climatic cycles, vegetation, lake stage and overflow, soil types, and basement geology. The geographic scope of the synthesis should encompass the entirety of the historic Everglades. This effort should be geospatially based for ease of facilitation into a GIS framework. The spatial databases generated in this task should provide the landscape framework for the spatially explicit hydrological models. Historic rainfall and climatic conditions should provide information for environmental correlates between hydrologic parameters and the resulting landscape processes.

- Perform paleogeologic studies to fill information gaps for model input. (These studies should encompass the entirety of the historical Everglades.) The analyses should be designed to utilize marker horizons (both isotopic and stratigraphic capable of depicting time specific event sequences and system responses through time.

Research Question 2: What hydrologic and associated forcing functions (fire, etc.) maintain the structure, function, and sustainability across spatial scales of km to 100's km of the South Florida ecosystem. Structure is considered spatial extent, heterogeneity of physiognomic features of the landscape and the associated large scale/small scale hydrologic gradients. Function is considered the delivery of water downslope (throughput), flow (rate), dynamic storage, head etc.

Approach

- Design a paleoecologic study based on stratigraphic analysis of cores strategically located throughout the Everglades. Through marker horizons (isotopic and geologic) develop a time series database for event sequences, frequencies and extent (both spatial and temporal). Conduct peat analysis to determine the following: peat accumulation rates (site and region specific); botanical analysis to determine historic dominant species composition and spatial extent of major vegetative landscapes (ex. wet prairie, saw grass, tree island complexes); fire frequency, extent, magnitude; and landscape successional trends and discontinuities.

- Through analysis of peat/marl structure and charcoal remnants determine extent, frequency, of drought, fire, floods, hurricanes, etc. Determine the correlation between these variables and the configuration and dynamics of historic vegetative communities within physiographic landscapes (as per Davis, 1943). The objective is to determine the interaction between vegetation, topographic gradients, and historic rainfall patterns on the hydrologic functioning of the system.

- Given the connection between basement topography and physiographic landscapes (Davis et. al 1994), determine relationship(s) between finer scale landscape features (tree islands, sloughs etc.), hydrologic (and hydrologically controlled) forcing functions, and basement topography. This task will require integration of synthesized extant information, paleoecologic and natural systems model studies.

Research Question 3: What is the nature and degree of the flow / hydropatterns alterations due to compartmentalization? How do current regimes of flow and hydropatterns depart from historic regimes driven by the natural hydrologic gradient that included sheetflow, system-wide dynamic storage, and was essentially rainfall driven? How has the landscape distribution of productivity and biotic diversity affected by the change from a predominantly diffuse large-scale processes (dynamic storage/sheetflow, and atmospheric deposition) to concentrated focused processes (canals, pumps, ditches, and point source of nutrients). More simply stated ...How has the landscape been impacted by the barriers, canals, and water management of the C&SF Project?

Approach:

- Analyze existing hydrologic conditions utilizing the SFWMD's SWMM model to characterize the current patterns in hydroperiod, flow, storage, and gradients in the WCA's. Current spatial scale of the SWMM model may require modification to address the above questions.

- Utilize the natural systems models (See Research Question 1) to characterize historic patterns of flow and hydropatterns prior to compartmentalization. These models should be developed utilizing historic topography reconstructed from archived data or modeled from best available information sources. Historic vegetation/landscape features should be incorporated as spatially explicit manning's coefficients.

- Existing models (both SWMM and current version of natural systems model, Fennema et al., 1994): require considerable enhancement to address restoration questions at the scale required by the above question. The following tasks would augment the current capability considerably:

    . conduct extensive and comprehensive topographic surveys in the WCA's.

    . determine specific manning's coefficients for various vegetative types (particularly vegetative types that dominate landscape features).

    . determine percolation within the various reaches of the WCA's.

    . improve the resolution rainfall data and water delivery patterns

    . validate model(s) with field measurements of water levels and flow.

- Compare output from current and historic models.

- Collect hydrologic data (flow, water level etc.) to supplement existing data and model output to document the nature and extent of hydrologic alterations.

Research Question 4: How are these alterations expressed in the existing landscape?

Approach:

- Conduct an extensive survey of peat bed depths across the WCA's and ENP. Determine the relationship between peat depths and current hydrologic conditions on the affected areas. Utilizing cores with stratigraphic time markers generated in other tasks (See Research Question 2) determine the correlations between peat accumulation rates and hydrologic regimes specific to the cored sites.

- Determine at various scales which patterns (elevation, vegetation etc.) in the contemporary landscape are the result changes in hydrologically controlled forcing functions as reflected in trend analysis and modelling.

    . Conduct a high resolution ($<$ 1km) topographic survey.

    . Perform spatial trend analysis of pre- and post-compartmentalization topographic data. This task will require synthesizing both historic and current information.

- Perform trend analysis (juxtaposition, location, abundance, orientation, succession) of pre- and post-compartmentalization vegetative features (saw grass prairie, wet prairies, sloughs, and tree islands).

- Perform trend analysis of pre- and post-compartmentalization fire frequency, extent, intensity, and effects.

- Compare landscape patterns between WCA1 and WCA2 to investigate the role of sheet flow in structuring the vegetative landscape.

- Perform gradient analysis to determine the relationships between hydrologic parameters and composition, abundance and distribution of periphyton and macrophytes. This task will require establishing permanent monitoring stations within a grid network traversing the various hydrologic gradients within the WCA's and periodically sampling vegetation plots for composition, % cover, and biomass. A protocol based on a stratified approach could be employed to vary the temporal and spatial intensity of the sampling.

- Utilizing the above information and the SWMM model determine relationships between recent vegetative patterns and dynamics with hydrologic (and associated) forcing functions spatially across the WCA's.

- Integrate information obtained above with the output of SWMM and natural systems models into a spatially explicit landscape modelling capability as per the Everglades Landscape Model (ELM)(See landscape modelling section of "Modelling Ecological Processes" of this document)of the SFWMD and compare the results for resolving the impacts of compartmentalization. A landscape studies/modelling program should be developed that supports and integrates with the hydrological modelling activities as well as the spatially explicit individually based ATLSS models being developed by the Oak Ridge National Laboratory and the South Florida/Caribbean Field Laboratory. The program should dovetail with complementary modelling efforts underway within the SFWMD and build on existing capability, expanding the geographic and temporal scope of ELM and integrating a hierarchical capability to refine pixel element size for specific applications.

Research Question 5: Is there adequate water available to support the desired system structure and functions? Is removal of the inter-unit dike and canal works of the WCA's feasible in terms of the current or projected demands for water in the South Florida Ecosystem?

Approach: The tasks outlined below require considerable integration of the information synthesized from the previous research questions in addition to compiling a system-wide hydrologic budget.

- Develop system wide (Kissimmee/Okeechobee/Everglades Watershed) water budget and projections of future water demands by consumptive users in the landscape (urban, agriculture etc).

- Develop a range of water requirements (volume, timing, placement, and conveyance requirements) to support critical natural system structure and functions. In-flow needs of the estuarine system are a critical element of this analysis.

- Determine the capacity of a restored system (an Everglades minus the water control structures that currently comprise the WCA's) to accommodate rainfall extremes while providing a significant capacity to absorb storm water run-off from the developed adjacent areas.

Research Question 6: Given the reduced spatial extent of the system, can adequate gradients and throughput be restored to support the freshwater inflow requirements of the downslope systems (i.e. estuarine and ENP) without sacrificing critical system structure and functions. Whole system integrity is one of the major tenets of the

restoration initiative. There is genuine concern that any restorative fixes not be conducted on one part of the system at he cost of the ecological integrity of another. The loss of approximately 50% of the original wetlands raises concerns regarding the conveyance capacity of the remaining wetland system to meet downstream inflow needs while maintaining desired ecologic structure and function.

Approach:

- Based on critical water needs (amount, timing etc.) of South Florida system components (estuary, urban, ag, northern Everglades, southern Everglades) investigate (feasibility, impacts etc.) various means for moving water from Lake Okeechobee to estuaries and southern Everglades.

- Enhance the landscape level modelling capability (ELM, as per SFWMD) to interact with both SWMM and "natural systems" hydrologic models. The enhanced model needs to be responsive to both hydroperiod/pattern and flow parameters in terms of predicting vegetative landscape responses. Investigate various scenarios of hydrologic restoration vs landscape structure and function that meet the down slope requirement for minimal inflow while providing the necessary hydrologic structure (flow pattern/hydropatterns) that sustain diverse structural landscape and vegetative mosaics for supporting a sustainable diverse flora and faunae similar to the historic conditions.

Research Question 7: What water quality is necessary to remove inorganic stressors on the system? What level of nutrients/contaminants trigger ecological impairment? The Everglades Surface Water Improvement Management Plan(SWIM), the Marjorie Stoneman Douglas Act (MSD), the Settlement Agreement between the U.S Department of Justice and the State of Florida concerning management of the Everglades, and the Everglades Forever Act (EFA) all either require or identify the need to numerically interpret the narrative Class III nutrient water quality criteria and to assess current and continuing response of the Everglades Ecosystem to nutrient loading. The following tasks are intended to provide information in resolution of these issues.

Approach:

- Conduct threshold studies for critical system components (periphyton, macrophytes, etc.). It is imperative to design appropriate experiments and bioassay techniques to be applied across the spectrum of ecological components of the system, ranging from individual species to communities, to even landscape features of the system to determine responses to the suite of both chronic and acute nutrient and other inorganic stressors impinging on the ecosystem. These studies will of necessity have to span approaches ranging from dosing studies in green house plots, to small plots in the field, to metered chronic additions to flumed portions of major habitat types, to analysis of known gradients that may span major landscapes. Considerable effort will be required in the experimental designs to assure spatial and temporal scales are appropriate to the questions be addressed.

- Perform gradient analysis of relationships between nutrients in water/soil and composition, abundance and distribution of periphyton and macrophytes. These analyses require establishing combinations of grid and linear transects across the geologic, hydrologic, and water quality gradients comprising the South Florida Ecosystem landscape. The intensity of the sampling should be a function of the steepness of the gradients and capture both the abrupt and continuous gradients associated with peat depth, substrate type, hydroperiod, water depth, and water quality gradients, particularly those reflective of the influence of agricultural drainage. Each site should be characterized for community composition, relative cover, and biomass of the macrophytic and periphyton communities. Samples of water and substrate should be taken for analysis of total phosphorus and nitrogen, conductivity, alkalinity, pH, hardness, bulk density (substrate only).
- Determine peat accumulation and nutrient sequestering capacity of vegetative communities along gradients of nutrient inputs. Specific sites across the gradient grid network should be established for long-term

monitoring/experimental manipulations in the form of dosing-type experiments for determining the nutritive assimilation capacity and specific threshold responses of biotic community to nutrient loadings. Considerable innovation in technique experimentation should be encouraged to facilitate determinations of biotic responses.

Research Question 8: What is the relative importance of hydrology and nutrients in modifying critical system components?

Approach:

- Perform multivariate analyses on the combined data sets of hydrology, nutrients, and composition, abundance and distribution of vegetation/periphyton generated in the gradient analysis described above.

ECOLOGICAL RESTORATION OBJECTIVES

- Restore predrainage populations of native flora and fauna, especially missing plant communities.
- Restore predrainage biodiversity.
- Reduce nutrient and contaminant import and export to levels that are adequate for maintaining ecological integrity.
- Control exotic plants and animals.
- Restore predrainage frequency and areal extent of fires to allow natural ecological processes to occur.

Research Question 1: What forcing functions, operating on scales from patches to landscape, control the distribution, abundance, and dynamics of: periphyton, plant communities (emergent-cypress) , aquatic invertebrates, fish, amphibians, reptiles, wading birds, snail kites, small mammals, and large mammals (deer, panthers).

Approach:

- Synthesize existing information, identify gaps, and design status and trend studies to determine the distribution, abundance, and population dynamics of the above groups.
- Determine the relationships (gradient analysis) between environmental factors (nutrients, contaminants, hydrology) and the distribution, abundance, and population dynamics of the above groups (gradient studies, impacted vs. unimpacted areas).
- Develop trophic relationships in the system (stable isotope ratios?, prey base studies, etc).
- Develop a family of models to investigate relationships between controlling variables and flora and fauna components. Model types will include but are not limited to population dynamics, species-habitat relationships, niche delineation, landscape pattern recognition, and spatial trend analysis on the distribution and abundance flora and fauna.
- Conduct studies to determine if fauna movements are altered due to compartmentalization (fish, amphibians, herps)

Research question 2: How can the predrainage vegetative landscape patterns be recreated within the context of existing spatial and hydrologic limitations?

Approach:

- Develop a set (hierarchical) of landscape succession models to examine restoration scenarios. (Based on analysis of water requirements for system components - see hydrology objectives)
- Develop indices of "ecological integrity" at scales appropriate to the individual target groups (periphyton - landscape)
- Conduct status and trend analyses of biodiversity as measured by vertebrate species richness (minimum).
- Combine information from natural system models with paleoecological data to determine correlations between hydrologic forcing functions and vegetative patterns and dynamics.
- Conduct time series analyses on from hydrologic models and relate to patterns in vegetation data.

Research Question 3: What constitutes impairment of ecological integrity?

Approach:

- Develop a suite of indices to evaluate ecological integrity.
- Conduct studies to compare faunal differences along gradients and extremes of water/sediment quality.

Research Question 4: What nutrients and contaminants are of concern?

Approach:

- Using information on local, regional, global sources and transport mechanisms develop a list of nutrients and contaminants that warrant investigation.

Research Question 5: What levels of nutrients and contaminants trigger impairment of ecological integrity?

Approach:

- Based on existing information on sources, transport, fate, and effect determine measurement endpoints for the nutrients and contaminants of concern.
- Conduct a system wide survey of nutrient and contaminant presence and/or effect using the appropriate endpoints.
- Develop threshold values for selected nutrients and contaminants via existing information, gradient analysis, or dosing studies.

Research question 6: What are the effects of exotics on system components and processes?

Approach:

- Map distribution and abundance of exotic species.

- Determine the linkages between the spread of exotics and alterations in critical ecosystem components and processes.
- Develop a procedure for prioritizing exotics for control.

Research question 7: What are the best methods to control exotics?

Approach:

- Investigate the use of biological controls for exotics.

- Determine which exotics may be controlled (or spread) by disturbances and changes in the forcing functions as a result of compartmentalization or restoration.

Research Question 8: What was predrainage fire frequency and aerial extent of fire?

Approach:

- Conduct coring studies to determine the extent and frequency of fire.

Research Question 9: Given the reduced spatial extent of the system, can patterns of fire frequency and extent be restored?

Approach:

- Integrate fire ecology into hydrologic models.

Overriding question: What constitutes sustainability of the system?

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APPENDIX 1

EVERGLADES RESEARCH PLAN

EVERGLADES RESEARCH PLAN EXECUTIVE SUMMARY

The Everglades Research Plan (ERP) describes research efforts that are deemed necessary to fulfill the legislative and judicial mandates for the reduction of pollutant loads to the Everglades systems over the next five years. The plan also identifies efforts, based on sound scientific and engineering principles, that are needed to provide increasingly effective water resource management tools for the future.

Four mandates drive ERP priorities and timetables: the Surface Water Improvement and Management (SWIM) Act, the Marjory Stoneman Douglas Everglades Protection Act (Douglas Act), the Settlement Agreement between the U.S. Department of Justice, the Florida Department of Environmental Regulation (DER) and the South Florida Water Management District (SFWMD), and the Everglades permit. These four mandates share the short-term goal of reducing nutrient loads to acceptable levels and the long-term goal of regulating nutrient sources in a larger systems management context to restore the physical, chemical, and biological integrity of the Everglades ecosystem.

MAJOR OBJECTIVES

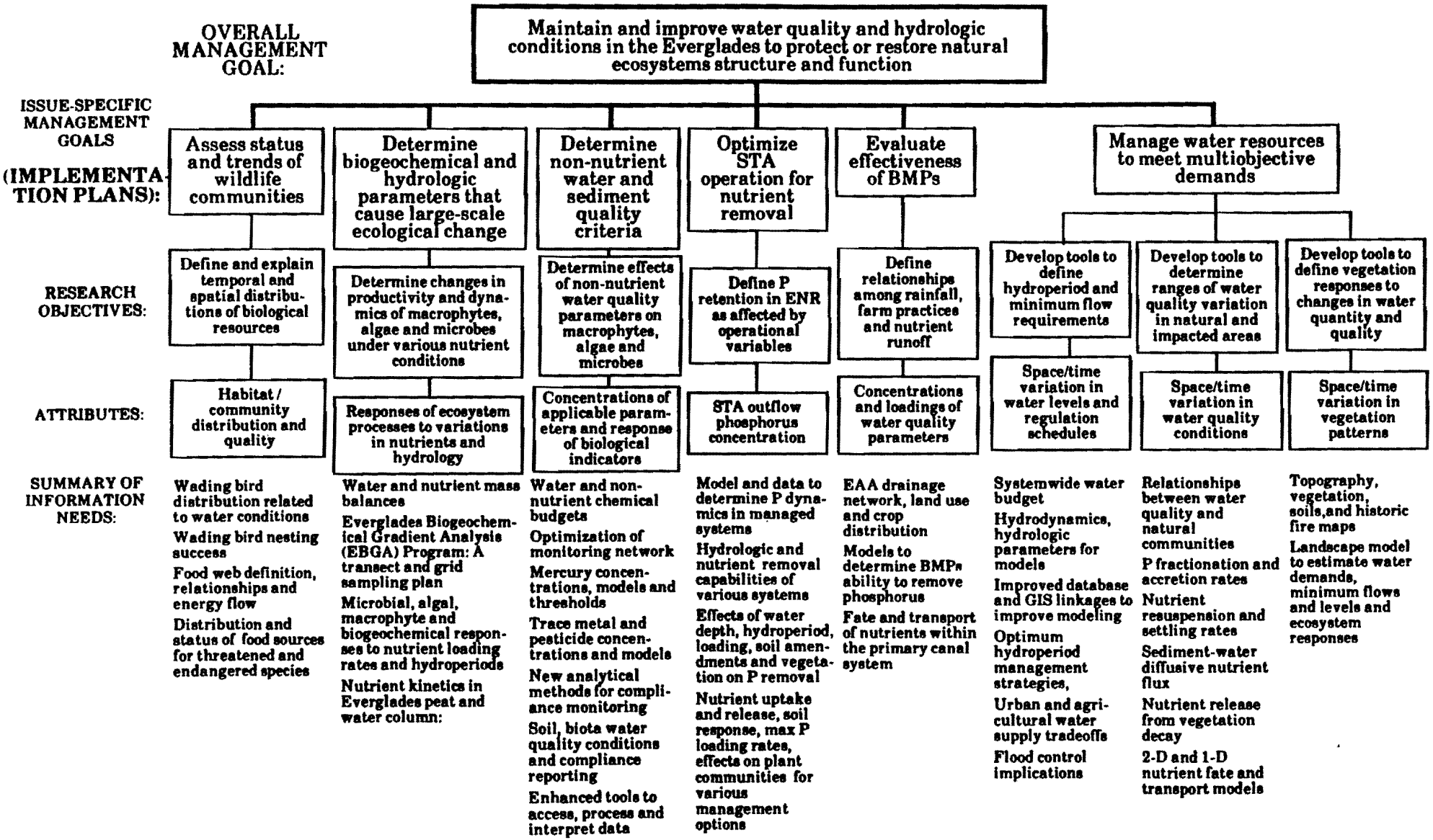
Six major Everglades management objectives and research programs to address these have been identified. These objectives and associated attributes and information needs are summarized in **Figure 2.** Each management objective will be addressed by one of six Resarch Implementation plansas follows:

Optimize Operation of Stormwater Treatment Areas for Nutrient Removal. Stormwater treatment areas (STAs) were designed, in conjunction with farm BMPs, to achieve about an 80 percent phosphorus load reduction from the EAA on average. Research is needed to determine methods that can be used to further reduce loads without increasoing STA size. Methods such as controlling hydroperiod and vegetational aspects of the STAs, may be critical to assure that they can perform to the design specifications, especially if research shows that "no imbalance" nutrient threshold concentrations are lower than the STA interim design outflow concentration. Investigations to optimize the nutrient removal capabilities of STAs will be conducted as part of the Everglades Nutrient Removal project test and treatment cells.

Everglades Ecosystem Processes (EEP): Analyses to Determine the Biogeochemical and Hydrologic Parameters that Cause Large-Scale Ecological Change. Research is required to understand how Everglades flora and fauna respond (e.g. changed productivity, nutrient cycling, species composition) to nutrient gradients and altered hydroperiod. This knowledge will enable managers to adjust water resource decisions towards achieving the goal of no ecological imbalance. This knowledge will also be used to parameterize, calibrate and validate models to predict potential biological change as a function of management decisions.

Develop Tools for Multi-Objective Management of Water Resources . When decisions are made concerning water quantity, implicit decisions are being made concerning water quality and ecosystems affected by water quality. Modeling tools will be built to explicitly examine tradeoffs among water quantity, water quality, and ecological integrity for existing, proposed and potential water quantity management scenarios. Establishing optimal flows and levels for maintaining the ecological integrity of the Everglades will be a key focus of this work. Remote sensing of vegetation changes and correlation with water quality trends and management practices through a GIS framework is central to the success of this research.

Figure 2. Everglades Research Goals, Objectives, Attributes and Information Needs



Assess the Status and Trends of Wildlife Communities. Documenting the status and long term trends of wildlife communities (e. g. wading birds, fish, etc). is important for understanding the ecological impacts of water management decisions. Such data provide a baseline for future years, and help quantify the natural variability of wildlife communities.

Evaluate and Optimize the Effectiveness of BMPs. The water quantity and quality of agricultural runoff is, among other factors, affected by crop type, soil type, local rainfall, and BMP design. Analysis of EAA runoff data and site characteristics should help understand runoff characteristics and what can be done to improve BMP performance.

Determine Non-Nutrient Water and Sediment Quality Criteria that Prevent Ecological Imbalance. Studies are needed to determine the extent to which non-nutrient water quality conditions in the Everglades comply with existing numerical and narrative standards, and to determine new standards where necessary to prevent ecological imbalance. The extent to which conditions change over time as a result of management actions will be documented using a mass balance framework to identify the relative importance of water quality sources and sinks. The effects of Stormwater Treatment Areas (STAs) and agricultural Best Management Practices (BMPs) on potential mobilization of toxic metals will be investigated, and food web bioaccumulation models will be developed to assess potential heavy metal risks to biota.

KNOWLEDGE ACQUISITION TIMEFRAMES

Implementation plans have been written to define necessary and sufficient research, modeling, and monitoring to address the six management objectives. The implementation plans (attachments 1 through 6) include details of proposed research, and estimated resources needed to accomplish it. The major knowledge gained from the research conducted, and the time course over which it is gained is outlined in **Tables 1 through 6.**

Table 1. Major Knowledge Gained from Implementation Plan: Optimize operation of stormwater treatment areas for nutrient removal.

	Year 1	Year 2	Year 3	Year 4	Year 5
•Phosphorus retention by natural Everglades wetlands (WCA2A)-	--> x				
•Laboratory determination of the effect of hydrologic conditions, soils and plants on nutrient uptake and release by wetlands-	- - - -	- - - - - -	- - - - -> x		
•Growth and fill-in rates of planted wetland systems for guiding STA planting decisions.	- - - -	- - - - - -	- - - - - -	- - - -> x	
•Field determination of the effect of hydrologic conditions, soils and plants on nutrient uptake and release by wetland sediments	- - - -	- - - - - -	- - - - - -	- - - -> x	
•Recommendations for operating STAs at highest P removal rate.-	- - - -	- - - - - -	- - - - - -	- - - - - -	- - -> x

Table 2. Major Knowledge Gained from Implementation Plan: Everglades Ecosystem Processes (EEP): Analyses to Determine the Biogeochemical and Hydrologic Parameters that cause Large Scale Ecological Change.

	Year 1 1 2 3 4	Year 2 1 2 3 4	Year 3 1 2 3 4	Year 4 1 2 3 4	Year 5 1 2 3 4
•Definition of measures used to define ecological change	- - - - - - - -	--> x			
• Class III water quality standards estimated from existing field and remote sensing data	- - - - - - - -	- -> x			
•Laboratory-derived responses of algae and microbes to nutrient gradients	- - - - - - - -	- - - - - - - -	-> x		
•Laboratory-derived responses of macrophytes to nutrient and hydroperiod	- - - - - - - -	- - - - - - - -	- - - - - - - -	-> x	
•Field-derived responses of water quality standards for microbes, algae, invertebrates and macrophytes to nutrient and hydroperiod gradients	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	-> x

Table 3. Major Knowledge Gained from Implementation Plan: Develop tools for multi-objective management of water resources.

	Year 1	Year 2	Year 3	Year 4	Year 5
•Baseline species distribution of vegetation in the WCAs and Holeyland	- - - - - - - -	-> x			
•Water quantity requirements of the remaining natural Everglades system (Natural-System Model)	- - - - - - - -	- - - - - - - -	- -> x		
•Relationships between water management decisions and large scale nutrient and vegetation dynamics (Preliminary results: Everglades Landscape Model and 1-D and 2-D water quantity-quality models)	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	--> x

Table 4. Major Knowledge Gained from Implementation Plan: Assess status and trends of wildlife communities.

	Year 1	Year 2	Year 3	Year 4	Year 5
•Quantification of trends in wading bird population abundance and distribution	- - - - - - - -	-> x			
• Quantification of trends in wading bird nesting success and food-availability.	- - - - - - - -	- - - - - - - -	-> x		
•Wading bird population dynamics as a function of hydrology and food availability.	- - - - - - - -	- - - - - - - -	- - - - - - - -	--> x	

Table 5. Major Knowledge Gained from Implementation Plan: Evaluate effectiveness of BMPs.

	Year 1	Year 2	Year 3	Year 4	Year 5
•Early baseline P runoff loads for each farm, adjusted for hydrologic variability	- - -	- - -> x			
•Effects of water management on the fate and transport of nutrients in EAA canals	- - -	- - -	- - -	- - -> x	
•Recommendations for maximizing efficiency of P retention by BMPs	- - -	- - -	- - -	- - -	- - -> x

Table 6. Major Knowledge Gained from Implementation Plan: Determine Non-Nutrient Water and Sediment Quality Criteria that Prevent Ecological Imbalance..

	Year 1	Year 2	Year 3	Year 4	Year 5
•Assessment of compliance with existing non-nutrient water and sediment quality standards in the Everglades.	- - -> x				
•Identification of major sources and sinks of non-nutrient water and sediment quality parameters.	- - -	- - -	- - -> x		
• Mercury distribution in soil and water throughout the EPA	- - -	- - -	- - -	- - -> x	
•Potential effects of STAs on heavy metal dynamics	- - -	- - -	- - -	- - -	- - -> x

EVERGLADES RESEARCH--TIME SCHEDULES, SUPPORT REQUIREMENTS AND AGENCY COST SHARE

Details of proposed projects, including task descriptions, projected time lines, capital, manpower and contractual support requirements, are provided in **Appendix B**. Many of the proposed projects are multi-year studies that will require continued commitment and support by the District and other agencies. **Table 7** provides a summary of estimated costs and manpower requirements to conduct the FY 94 portion of the Everglades research effort. However, actual amounts spent on contracts and equipment during FY 94 will depend on initiation dates of contracts and research. **Table 8** provides a summary of estimated total costs for priority projects during a four-year Everglades research effort, from FY 94 through FY 97.

Table 7: Priority Project FY 94 Contract and Equipment Costs (x$1000) and Full Time Equivalents (FTE) Personnel Requirements

Management Objective	Contracts[1]	Equipment[1]	Personnel Usage[1,2]
Manage water resources to meet multi-objective demands	1,280	28	12.2
Optimize STA operation for nutrient removal	204	0	12.0
Evaluate effectiveness of BMPs	0	0	0.0
Everglades Ecosystem Processes: Determine biogeo-chemical and hydrologic parameters that cause large-scale ecological change	1,046	410	4.7
Assess status and trends of wildlife communities	280	0	1.8
Determine non-nutrient sediment and water quality criteria	356	1	2.3
TOTALS	3166	439	33

1 Costs for Priority 2 activities (see Appendix B) are not included . Costs shown include only DOR. Costs for other Departments are not included. Salary costs and overhead are not included.

2 Total FTE does not add up to the number of Division positions. Variable amounts of time, depending on the position, were allocated to other Everglades support activities, supervision, administrative duties and leave.

Table 8: Priority Project Total Contract and Equipment Costs (x$1000) and Personnel Requirements for a Four-Year Everglades Research Effort.

Management Objective	Contracts[1]	Equipment[1]	Total Program Cost[1]	Person-Years[1,2]
Manage water resources to meet multi-objective demands	3580	28	3608	40.1
Optimize STA operation for nutrient removal	1944	306	2250	35.1
Evaluate effectiveness of BMPs	0	0	0	0.0
Everglades Ecosystem Processes: Determine biogeo-chemical and hydrologic parameters that cause large-scale ecological change	7025	748	7773	18.8
Assess status and trends of wildlife communities	1220	0	1220	6.0
Determine non-nutrient sediment and water quality criteria	609	99	708	9.1
TOTALS	14,378	1181	15,559	109.1

1 Costs for Priority 2 activities (see Appendix B) are not included . Costs shown include only DOR. Costs for other Departments are not included. Salary costs and overhead are not included.

2 Total FTE does not add up to the number of Division positions. Variable amounts of time, depending on the position, were allocated to other Everglades support activities, supervision, administrative duties and leave.

SUBREGIONS 6 & 7:

BIG CYPRESS BASIN AND EVERGLADES NATIONAL PARK (MAINLAND PORTION)

INTRODUCTION

Sub-region 6 comprises the Big Cypress watershed north to the Caloosahatchee River watershed including the Panther National Wildlife Refuge and the Fakahatchee Strand. Sub-region 7 consists of the non-marine southern Everglades region and is coincident with the freshwater and terrestrial portions of Everglades National Park and the adjacent authorized East Everglades acquisition lands. The two sub-regions have been combined into a single report because of the evident ecological connections between the two areas and their similar research needs and restoration goals. In fact, however, many of the information needs and restoration goals apply as well to all hydrologically connected areas in south Florida. Thus as the discussion below suggests, many of the pressing research needs described for Sub-regions 6 and 7 apply also to Sub-region 5, the Water Conservation Areas.

The approximately 462,000 acres of land in South Florida considered Indian lands comprise an integral part of the ecosystem. The largest tracts are the Big Cypress Seminole Reservation; the Miccosukee Reservation; the Brighton Seminole Reservation northwest of Lake Okeechobee; and much of Water Conservation Area 3A, which is perpetually leased by the State of Florida to the Miccosukee Tribe. Since all of the Big Cypress Seminole Reservation and one-third of the Miccosukee Reservation are contained in the Big Cypress Basin, discussion of research needs for Indian lands is included in this section on Sub-regions 6 and 7.

The large areas comprising Sub-regions 6 and 7 are distinguished by the large proportion of officially designated wilderness area (in Everglades National Park) and the federal ownership for controlled use purposes of nearly all the area. Thus the ecological problems of the area result primarily but not wholly, from forces originating outside the sub-regions. Nevertheless both the ecological problems and their restoration-related information needs are substantial. Solutions to the problems must necessarily arise from restoration actions applied over the larger regional ecosystem but will be measured within the sub-regions themselves. Given this situation, the writing team decided to approach the question of research needs in the context of major ecological issues.

Issues of most concern and associated critical questions are identified followed by a brief statement of the recommended approaches. Neither the list of issues nor of questions is intended to be exhaustive. Rather, the most fundamental of each is described. The most fundamental concerns in these sub-regions, particularly as they relate to the concept of restoration of the regional ecosystem can be articulated as the need to understand the nature and implications of *ecological change within Sub-regions 6 and 7.* The changes include all those known or suspected to have occurred in the sub-regions since the period prior to the earliest organized drainage enterprises of the late 19th century. The following discussion is therefore organized accordingly.

MAJOR ISSUE: Changes in the hydrological cycles within the system. These include for example, water level and water flow changes, meteorological changes, such as rainfall and evapotranspiration patterns and changes in the flow regimes.

Background

Declining water levels in the Everglades and Big Cypress have only recently been documented. Historical information in the basins is sparse and mostly anecdotal. The earliest continuous water level information within the Everglades started in 1952 and in Big Cypress in 1965. Early drainage operations in the northern Everglades undoubtedly had some effect in the southern Everglades. Then, as development moved south along the coastal ridge

and adjacent lands drainage accelerated by first, channelization of the coastal rivers and the removal of the rapids, e.g., Miami River, and second, dredging and cutting of canals through the coastal ridge along the entire lower east coast, e.g., Snapper Creek canal, Miami canal and New River canal. These drainage projects brought noticeable differences to the water levels adjacent to and in the Everglades. No continuous record exists to document the early declines of the water levels, however, much knowledge about the hydroperiods and hydropatterns can be obtained from examining physical (such as soil descriptions) and ecological (such as vegetation communities) data.

Uncontrolled flow to the southern Everglades was impeded by construction of the first east-west road, Tamiami Trail, in 1928, the canal dug for the road fill also being used for drainage. Parker et al. (1955) reported that Dade County water levels had dropped by as much as 6 feet by 1955. Towards the west and southwest these water level drops were not as large, but surface water patterns were altered and interrupted. The start of construction for the Eastern Protective Levee system in 1952 reduced the flow from the western glades and the construction of large impoundments north of Tamiami Trail into Water Conservation Areas, essentially stopped all natural sheet flow into Everglades National Park (ENP) and Big Cypress (BC).

Current flow patterns in the Everglades National Park are very much influenced by management of the impoundments to the north, extensive agricultural and urban pumping, and the drainage canals to the north and east. Unnatural hydroperiods and hydropatterns, as compared to the historical hydrologic conditions, are the norm, resulting in sharp reductions of seasonal water levels and large discharges for flood control purposes. Although Big Cypress initially did not have the development pressures like the eastern Everglades, recent urban and agricultural expansion have caused the lowering of the water tables to the north of the preserve and most likely are affecting the water patterns within Big Cypress.

Hydrological restoration efforts in the remaining wetlands are based on the re-establishment of natural hydroperiods and hydropatterns. In order to define what these natural water levels should be, considerable knowledge is required on pre-drainage and historical hydrology. In addition to developing this fundamental knowledge, implementation of restoration scenarios will require research on many of the hydrological processes to improve the required parameters and data bases needed for interpretation.

Spatial Aspects: Water level declines have occurred throughout the Park, the major declines occurring along the eastern Park boundary in Northeast Shark Slough, Rocky Glades and northern Taylor Slough. At times, western Shark Slough receives large regulatory releases, substantially altering natural water patterns, transforming the area from what were originally peripheral wetlands into a main flow way. Water level declines in Big Cypress originate along the northern boundary and extend southward.

Current Research

Several aspects of the hydrology of Sub-regions 6 and 7 are under active investigation. These are summarized below. Extensive monitoring of stage levels also is ongoing. Fifty stations are active throughout the freshwater Everglades and 12 in the Big Cypress National Preserve.

Water Delivery Studies:

Shark Slough Experimental Water Delivery Evaluation:

This project will continue assessing the current rainfall-based water delivery formula and its hydrologic impacts on the Shark Slough basin through 1994. The results will then be combined with biological assessments by Everglades National Park (ENP) and National Biological Survey (NBS) staff, with a final report expected in early 1995.

An Assessment of Changes in Discharges and Resulting Marsh Water Levels in the Lower C-111 Basin in response to the C-111 Interim Project:

This project is a continuation of a South Florida Water Management District (SFWMD) contract which includes monitoring and research efforts to assess the impacts of the C-111 Interim Project on the wetlands in the lower C-111 basin. Additional quarterly and annual reports will be prepared during FY95.

Management of Water Levels in the C-111 Basin, and Urban Runoff Retention:

This project is a continuation of a SFWMD contract that focuses on an analysis of the operation of the L-31N, L-31W, and C-111 canal systems related to water management improvements to conserve wet season runoff and improve dry season water supply. A final project report will be prepared during late FY95.

Taylor Slough Demonstration Project Assessment:

This is a continuation of ENP's assessment of the impacts of the Taylor Slough demonstration project on the hydrologic resources of the Taylor Slough basin. During the second year of the project the SFWMD will begin structural and operational studies to implement the Emergency Interim Project required by the Everglades Forever Act.

Taylor Slough Delivery Formula Testing:

In 1994 a new rainfall/stage relationship for the Taylor Slough basin was developed based on historical water level and rainfall data from the period from 1933 through 1947. Follow-up analyses are needed to describe how this formula should be implemented during the next year of the experimental program, and the impacts that would be expected under this new delivery approach.

Shark Slough Delivery Formula Development/Testing:

ENP is establishing a new cooperative agreement to develop a revised rainfall-based delivery formula for the Shark Slough basin, which is expected to be completed by early 1995. This new formula would be based on early post-drainage hydrologic data for the Shark Slough basin, as well as the results of National System Model (NSM) simulations. Once the formula is completed, it will require a detailed testing phase using South Florida Water Management Model (SFWMM) simulation runs, similar to the one described above for Taylor Slough.

Shark Slough Modified Water Deliveries FDM Assessments:

This new project would perform detailed investigations of the hydraulic design elements and operational criteria for the Corps Feature Design Memorandums (FDMs) for the Modified Water Deliveries Project. This project would produce a series of brief summary reports that would focus on specific design features of the project.

Numerical Modeling Studies:

Natural System Model Improvements:

ENP is continuing work on improvements to the current version of the Natural System Model. Our efforts during FY95 will focus on the development of a 1 square mile version of the NSM for applications within the Park. A draft report by ENP hydrology staff is expected in early 1995.

Regional Hydrologic Assessments/Restoration Modeling in the Everglades:

An initial assessment of the early post-drainage hydrologic conditions throughout the Everglades ecosystem was started by ENP hydrologists in 1990. During FY95, additional assistance will be provided by Florida International University (FIU) and South Dakota State University (SDSU). We hope to combine the results of these investigations with detailed analyses of simulations using the 4 square mile version of the NSM model to develop hydrologic restoration targets for the overall Everglades ecosystem.

Operational Studies - Modified Water Deliveries and Canal 111 GRR:

A detailed hydrologic and environmental assessment will be needed to assist in defining structure operating guidelines that will maximize the ecosystem restoration goals of these projects. There is currently no funding source to support this type of an assessment.

C&SF Restudy/South Florida Ecosystem Restoration Support:

In 1995, ENP and its cooperators will assess current water management practices in the south Florida region, document their impacts on the ecosystem, and develop and evaluate needed structural and operational improvements. The work will support the South Florida Ecosystem Restoration Initiative. All of these tasks will require extensive hydrologic modeling efforts using the NSM and SFWMM.

Critical Questions and Research Approach

1. How does evapotranspiration rate vary across vegetation type and soil type and depths?

Approach: A large, but little known, component of the water budget needs to be better defined for use in the calibration and verification of models and water budgets. Set up field measurement stations at six different communities within the freshwater Everglades and Big Cypress basin for long-term monitoring.

2. What are the spatial characteristics of the shallow aquifer below the freshwater Everglades and Big Cypress basin?

Approach: Very little subsurface information exists on the shallow aquifer's depths, transmissivities and storage coefficients. A field program is needed to better define these parameters. Test wells and core analysis coupled with surface geophysics will be included for a comprehensive analysis of the subsurface.

3. What are the land elevations in the western sections of the freshwater Everglades and the entire Big Cypress basin?

Approach: Approximately 50 percent of the freshwater Everglades has not been surveyed and none exists in the Big Cypress basin. This is a fundamental data set and is needed for all hydrological and ecological modeling and analysis. Conventional surveying coupled with testing of remote techniques will be used.

4. What are the overland flow characteristics in the wetlands of the freshwater Everglades and the Big Cypress basin?

Approach: In order to quantify wetland flows and freshwater releases to the estuaries the basic parameters relating to flow resistance are needed. Parameter determination using both laboratory and field experiments will be conducted.

5. What are the infiltration rates in different soil and vegetation communities of the freshwater Everglades and Big Cypress basin?

Approach: This parameter is used in water budget calculations and hydrologic modeling and quantifies seepage between the surface water and ground water. Field studies will be conducted in areas with different soil characteristics.

6. What are the ground water seepage rates to the canals and estuaries?

Approach: Large seepage flows are known to occur from the natural areas to the canals along ENP's eastern boundary and from the canal to the natural areas along the northern boundaries of BC and ENP. Also, both

surface and ground water flows to the lower estuaries have not been quantified. Using both test wells and flow meters these flows will be better defined during a long term field study.

7. What are the rainfall/runoff relationships and the natural variability of water levels within the freshwater Everglades and Big Cypress basin?

Approach: To determine the operational schemes that promote BC and ENP restoration, relationships between stages, flows and rainfall need to be established to guide water managers. Using physically based and statistical models, formulas will be refined, developed and evaluated to guide water deliveries to the natural areas.

8. What are the pre-drainage hydroperiods and hydropatterns within the freshwater Everglades and Big Cypress basin?

Approach: This information is needed to guide the restoration effort. Comparisons can be made between the pre-drainage and drainage periods to evaluate natural spatial and temporal water distributions within a reduced Everglades. Using historical information and models these relationships will be developed and analyzed. .

MAJOR ISSUE: Significance of Soil Changes in Sub-regions 6 & 7 for Hydrological and Biological Restoration of the Everglades.

Background

Evidence indicates that artificial drainage of the greater Everglades and associated urban and agricultural development have caused changes in the soils of the Everglades region. The most widespread effects appear to be the loss of surficial organic soils in freshwater marshes as a result of accelerated oxidation of soil organic matter because of lowered surface and ground water levels (Craighead 1971). A second important loss of organic soils is traceable to wildfire which is believed to be more severe and widespread as a result of artificial drainage, but also varies considerably in spatial extent and severity as a consequence of droughts (Craighead, 1971).

Soil formation rates are little known for the marl and peat types in the region, but are relatively high for the latter and low for the former. The qualitative role of vegetation in the form of arboreal, macrophyte or periphyton in forming the broad soil types is generally known, but how and why the rates differ is not. In coastal areas, strong hurricanes move large quantities of sediments around, reshaping ground elevations, creating or destroying natural levees and otherwise modifying topography (Wanless,pers. commun.). Such episodic processes influence vegetation development and local hydrology and therefore animal habitat over extensive coastal areas that extend into the freshwater Everglades.

In the larger system context, the overall soil mass influences the hydrologic dynamics of the Everglades in several ways. By mantling the limestone substrate with varying depths of sediment accumulation, local topography is modified. Variations in topography, in turn, influence sheet flow dynamics, ground water recharge and seasonality of flows and hydroperiods thus helping to define wetland hydrological characteristics. Soils also contribute to the timing and storage components of the water budget through such properties as hydraulic conductivity rate and water retention capacity. Deep peat deposits, for example, store water long after precipitation events, thus mediating a gradual, lagged release of water long after the cessation of the wet season. In this sense, an intact regional soil mass played a vital role in determining the characteristic timing of marsh flows and levels.

On a more local scale the distribution and depth of peat and marl soils and associated. characteristic vegetation types (including periphyton) structure habitat for terrestrial and aquatic animals. Changes in soils, whether natural or man-caused, alter this function, creating new vegetation types and related animal communities. As an example, burn-out of peat deposits in tree islands converts arboreal vegetation to herbaceous marsh, willow-heads, or shrub stands

depending on elevation and depth of burn-out (Wade et al 1980). Loss of surficial peat deposits from chronic overdrainage also affects aquatic food chains through reduction of the herbivorous food base. Local populations of many species are thus affected by organic soil losses, including tree snails, wading birds and alligators.

Spatial aspects: Most of the known or suspected soil changes have occurred within Sub-region 7, particularly in the Northeast Shark Slough area, Rocky Glades and adjacent Taylor Slough. Reduction in peat depths also seems likely in Shark Slough proper, but little evidence is available for drawing conclusions. Alteration of deposits related to hurricanes are to be expected in the southwest area, on the mainland north of Florida Bay, Cape Sable and along the Gulf Coast. Note also that major changes in soils probably have occurred in the adjacent Water Conservation Areas with consequences for hydrology and habitat in Sub-regions 6 and 7.

Current Research

Little research on soils is being conducted in the sub-regions, except that incidental to other topics such as mercury accumulation in sediments. The Center for Climate Research of the University of Wisconsin is, however, engaged in an analysis of sediment cores taken from a wide area including Water Conservation Area 3, the Everglades and the Florida Keys. The study's purpose is to reconstruct historic vegetation patterns and infer hydrologic conditions from paleoecological materials. Results are expected in late 1995.

Critical Questions and Research Approaches

1. What are the formation rates of the major soil types and what are the critical hydrologic and vegetation factors determining the rates?

Approach: Estimate past formation rates from isotope activity profiles. Estimate present and future rates by creating marker horizons or other procedures for measuring accretion of soil materials in major ecosystem types in Sub-regions 6 and 7.

2. Over what area have soils been altered as a direct and indirect result of overdrainage?

Approach: Complete modern soil survey across Sub-regions 6 and 7. Compare results with past surveys. Combine with survey data from adjacent areas. Include estimates of hydraulic properties, total mass and volume, state of decomposition and related characteristics in relation to spatial pattern.

3. Within the major basins that have experienced alterations, what are the estimated volumes (area and depth) of soil losses and how has the local topography been affected?

Approach: Use historical dating of sediments in areas to reconstruct soil depth profiles and determine age of surficial layers. Compare present soil composition and depth to predicted soil composition as inferred from vegetation pattern.

4. How have the relationships between vegetation and soil types changed since pre-drainage times?

Approach: Develop a model of landscape vegetation-soil dynamics that allows for hindcasting of soil formation dynamics from historic vegetation data. Some of the latter cost would be absorbed by completing a soil survey (see above). Include treatment of periphyton calcite formation and marl soil formation and how these processes vary with changes in periphyton composition and mass.

5. What is the significance of the soil changes for sheet flow and ground water recharge?

Approach: Simulate hydrology of selected sub-basins within the region incorporating explicit simulation of soils based on measurements of soil physical and chemical properties.

6. What is the role of the major organic soil and marl soil types for aquatic food chain support?

Approach:

a) Conduct field, laboratory and mesocosm studies of mineralization and uptake of nutrients from common organic and marl soil types in natural systems. Note that some of this work is proposed below under aquatic invertebrates.

b) In related work, investigate transfer of soil generated nutrients into aquatic food chains. Determine, through field and mesocosm studies how uptake and food chain transfers vary with habitat, soil type and hydrology. Note that some of this work is proposed below in the water quality section.

MAJOR ISSUE: Changes in water quality in the Everglades.

Background

The historic Everglades was a hardwater, oligotrophic system depending primarily upon rainfall for nutrients. Flows from Lake Okeechobee periodically augmented the northern Everglades's supply of nutrients, suspended organic particles, dissolved organic, and other materials. Now the Everglades is subject to intense disruptions of geochemical processes due to human activities. along its margins, and to some extent from atmospheric transport processes. With the advent of many intense land use changes, notably the drainage and cultivation within the Everglades Agricultural Area, development of the eastern coastal ridge, phosphorus and other materials are delivered to the Everglades in quantities significantly above historic levels. The consequences of such enrichment can be understood from the extensive development of cattail stands in phosphorus enriched areas formally dominated by sawgrass (Doren et al 1994).

The Everglades is protected by, among other standards (including nondegradation standards), Florida's Class III narrative nutrient standard. This standard requires that nutrient additions shall not be permitted at levels which cause an imbalance in fauna or flora. Present technology to treat agricultural runoff, the primary source of excess phosphorus currently reaching the Everglades in large amounts, is expensive and untried in the oligotrophic range for phosphorus. Thus there is great interest in determining the "threshold" number which when adopted will represent a maximum concentration which can be delivered without harm to natural communities of the Everglades.

The agricultural industry has spent several million dollars in determining that level by field dosing studies in WCA-2B. The state is embarking upon a $6.6 million effort, based upon transect and field mesocosm research, but believes controlled dosing in channels is not feasible or necessary. However many scientists feel that direct application of nutrients under controlled hydroperiod will be necessary to determine a protective phosphorus standard, as outlined in the TOC's 1992 report. The federal members of the TOC have recommended that such studies be implemented immediately.

The Department of Environmental Protection will make the final determination of the standard through their administrative procedures to report a number by 2001.

Current Research

The sole research activity in the two sub-regions at present is an field-intensive, multi-channel dosing study being planned for the freshwater Everglades in Shark Slough within ENP. The project is presently undergoing research design refinement and peer review and will begin in next fiscal year. Results are expected to satisfy administrative needs to determine a field threshold for phosphorus effects in the freshwater Everglades and provide much basic data on nutrient dynamics and ecological effects.

Critical Questions and Research Approaches

1. What levels of biogeochemical disturbance are compatible with the restoration and preservation of a viable Everglades system?

Approach:

a) Estimates of rates of influx, storage, recycling, and loss to the Everglades system are fundamentally important. Mass balance models are a first step and can be constructed from available information. More refined models requiring new data gathering efforts can then be prescribed and assembled.

b) Finer scale models of process dynamics for phosphorus, nitrogen, selected ions (including mercury) should simultaneously be initiated to refine internal cycling relationships, including the dynamics of movement and accumulation in the food web.

c) Special emphasis in both large scale mass-balance models and fine internal process investigations should be dedicated to the role of organics, both dissolved and particulate, in the evaluation of the natural and culturally impacted biogeochemicals of the modern Everglades.

2. What threshold value for total phosphorus can be released to the Everglades system from the Everglades Agricultural Area, eastern ridge urban development, and the southeastern catchment basin?

Approach: Develop an experimental design with adequate statistical power and reliable technology to provide accurate concentrations and flow measurements under rigorous field conditions. Implement the design in appropriate areas of the Everglades system; collect a minimum of 3 years of field data.

3. What sources, modes of transport, interaction with organic matter, and sinks exist for pesticides used on the periphery of the Everglades? What are the pathways for bioaccumulation into the food web of the Everglades? What additional monitoring of these phenomena is necessary?

Approach: Much of the current monitoring for pesticides may detect some of the compounds because they are bound to the high organic content of the inflows to the Everglades. Additional research to determine the compounds currently in use, the timing of usage, the interactions likely to occur within the water column and within sediments is necessary. Small scale field and laboratory projects are required.

4. What are the full effects of water quality decline on the plant and animal communities of the Everglades?

Approach: A great deal of new research and monitoring has been initiated by the recent litigation. Follow-up studies which replicate sampling of water quality and plant responses along transects in the WCA's and Everglades National Park are needed to document future trends. Particularly needed are replicated field studies of community and species functions and properties from sites located along transects that are accurately characterized as to sediment, water column, detritus and biomass content of N and P. Related work should include mesocosm and laboratory studies of the effects of nutrient additions and changing ratios upon periphyton, macrophytes, decomposers and short-lived consumers.

MAJOR ISSUE: Vegetation Changes.

Background

The vegetation of the two sub-regions is controlled to a large degree by a few interrelated factors, including elevation, substrate characteristics, hydroperiod, water depths, and several aspects of fire (Craighead 1971, Gunderson 1994, Duever 1984, Robertson 1953). Disturbances such as freezes (Olmsted et al. 1993, hurricanes (Armentano et al. 1994), droughts (Craighead 1971) and nutrient enrichment (Doren et al. 1994) also play a role

in determining vegetation structure and function. Human-induced changes such as modification of hydrology, altered fire regime, loss of organic soils and the introduction of exotic pest plants have caused both obvious and subtle changes in vegetation (Kolopinski and Kiger 1969, Alexander and Crook 1984, Ewel 1986). Distinguishing natural from anthropogenic sources of vegetation change is important for evaluating restoration success. Although vegetation in Sub-regions 6 and 7 for the most part is relatively little altered compared to other sub-regions, evidence suggests that important components of the freshwater and terrestrial vegetation of the region (especially Sub-region 7 but also to some extent Sub-region 6) are in disequilibrium with respect to present hydrology, soils and fire regime.

Numerous general descriptions of vegetation in ENP and BC exist. The report and map of Davis (1943) present a comprehensive overview of south Florida vegetation. BC vegetation has been mapped by McPherson (1973) and has a digital GIS map based on interpretation of 1984 photography. Currently the University of Georgia is developing a before- and after-Hurricane Andrew vegetation map of ENP, BC, and Biscayne National Park that would represent the first detailed map of the combined area. Several relatively small scale vegetation maps have already been completed for selected areas of ENP and BC (e.g. Olmsted et al. 1980; Olmsted et al. 1983; Gunderson and Loope 1982a,b). Unfortunately, there is no systematic program to monitor vegetation in ENP and BC. Those permanent plots that exist are neither well documented nor routinely sampled. However a series of aerial photographs exists for most of the area dating back 30 years or more. Changes in physiognomy over the last few decades can be detected by comparing remote imagery, but more subtle changes in species composition cannot.

Current Research

Most of the previous vegetation research in subunits 6 and 7 is related to exotic plants (e.g., Loope and Dunevitz 1981, Ewel et al. 1982, Myers 1983, Doren et al. 1991) or fire (e.g., Hofstetter 1984, Herndon and Taylor 1986, Snyder 1986, Spier 1991). Current studies concentrate on the impacts of Hurricane Andrew on the structure of forested communities: mangroves, hammocks and pinelands. A table summarizing all currently active hurricane response studies is given. Note that the entire National Park Service program is presented including studies in coastal areas that fall within Sub-region 8.

Research Projects Funded by the National Park Service
Hurricane Andrew Program (1992-1995)

The following projects address hurricane effects and response processes for specific ecosystems in areas crossed by Hurricane Andrew:

Investigator	Topic	Institution	Funding Instrument or Type
Oberbauer & Koptur	Responses of Four Non-tidal Forests Types	Florida Intn'l. University	CPSU
Slater & Platt	Hardwood Hammocks of Long Pine Key	Louisiana State University	Suppl.
Platt	Slash Pine Forest Structure and Demography	Louisiana State University	Suppl.
Ross & Meeder	Rare Plants in Pine Rocklands	Florida Intn'l. University	CPSU
Snyder & Koptur	Plant Response to Fire in Pinelands	Big Cypress National Preserve	CPSU

Investigator	Topic	Institution	Funding Instrument or Type
Hartman	Exotic Spread & Invasibility: Schinus and Melaleuca	Rutgers University	New
Trexler	Structure & Function of Freshwater Aquatic Communities	Florida Intn'l. University	CPSU
McKenna	Fish Community Effects in Mangrove Habitats	Florida Department of Natural Resources	New
Welch	Vegetation Map/ Digital Database: EVER, BICY, BISC	University of Georgia	New
Sparks & Bennetts	Effects on Tree Snails	Big Cypress National Preserve	New
Robson	Effects on Short-tailed Hawk Status	Florida Freshwater Fish and Game Commission	New
Emmel	Effects on Schaus Swallow-tail	University of Florida	New
Szmant	Effects on BISC Coral Reefs	University of Miami, RSMAS	CPSU
Jones	Water Quality and Biochemistry in Coastal Areas	Florida Intn'l. University	Suppl,
Wiebe	Nutrient Fluxes-Algal Mats, Mangrove and Seagrass on Gulf Coast	University of Georgia	New
Wanless & Tedesco	Sediment Re-distribution and Deposition	University of Miami	CPSU
T. Smith	Effects on Structure and Function of Gulf Coast Mangroves	Florida Department of Natural Resources	New
Twilley	Resource Utilization in Gulf Mangrove Communities	University of Southwest Louisiana	New
Robertson	Bald Eagle - Osprey Census	EVER/BISC/ BICY	EVER
Meyer & Robertson	Pineland Bird Survey Declines and Extirpation	BICY/EVER	EVER
Bass	Cape Sable Sparrow Census	EVER/BICY	supported by USFWS

Investigator	Topic	Institution	Funding Instrument or Type
Jansen	Red-cockaded Woodpecker	BICY	BICY

Results of a rapid survey of prompt hurricane effects on aquatic, marine and upland systems in the three south Florida mainland national parks were published in a special issue of BioScience (April 1994; Vol. 44, No. 4). More detailed information on residual effects one to two years after the storm is being collected and analyzed. Several reports have been submitted or are in preparation (effects on forests are summarized in Armentano, et al. 1994).

Critical Questions and Research Approaches

1. What changes have occurred in the south Florida vegetation pattern since the pre-drainage era? How can we detect future changes?

Approach:

a) Conduct paleolimnological studies of Deep Lake and other similar features to document changes over the last few thousand years.

b) Using available imagery and field data, document changes that have occurred over the last several decades.

c) Develop a comprehensive vegetation monitoring program using a combination of remotely sensed imagery and permanent plots. .

2. What have been the environmental factors responsible for the observed changes in vegetation structure? What is the relative importance of the different factors in causing change?

Approach:

a) Conduct field experiments which include manipulation of suspected factors, including hydroperiod, water depth, water quality, substrate, and fire.

b) Develop a process model of vegetation development for selected major vegetation types based on results of field experiments and on relationships of vegetation pattern to site characteristics at a large number of sites.

3. Within areas where a given vegetation cover type has persisted since the pre-drainage era, what changes have occurred in composition and productivity?

Approach: Within major vegetation types, measure accumulated standing crops and estimate present rates of primary production using standard harvest methods and repeated sampling appropriate to habitat and vegetation type. Compare areas differing in present condition and recent history (e.g., in sawgrass stands, select sites of known fire histories and those subject to sawgrass decline and altered flooding regime; include dense and sparse stands). Conduct sampling at sites well documented as to soils, topography and hydrologic characteristics. Begin developing a stand development or growth model driven by the main abiotic forces. This model should be constructed so as to receive hydrologic inputs and treat stochastic events such as fires and freezes.

4. To what extent is plant succession a factor in determining vegetation composition and development?

Approach: Reconstruct historical patterns based on archival information. Determine fire, hurricane and freeze chronologies for documented sites. Review botanical literature from other hurricane-prone regions. Establish temporal trends for selected sites using earlier studies (including Hurricane Andrew plots) and archived information.

Continue plot analysis where plot locations from past studies can be determined. Establish a permanent plot network with standardized sampling to evaluate future trends.

5. What is the status of special (rare or listed) plant populations? How can the long-term survival of these populations be assured?

Approach:

a) Design and implement a monitoring program for populations of special plant species.

b) For species suspected to be in decline, conduct detailed studies of population dynamics, including manipulative experiments, if necessary.

6. To what extent have exotic species disrupted natural community function and what needs to be done to minimize these effects? What exotic species may pose problems in the future?

Approach:

a) For the area as a whole and for sites differing in extent of invasion, determine through field studies how community characteristics have been altered.

b) Improve control strategies for known problem species through integrated use of herbicides, biological control, and mechanical control including fire.

c) Develop autecological profiles for anticipated problem species. e.g., *Neyraudia* and *Rhodomyrtus*.

MAJOR ISSUE: Decline and alteration of freshwater fish productivity and diversity.

Background

In the Everglades and Big Cypress wetland systems, natural environmental conditions regularly vary seasonally, annually, or on a multi-annual basis. The effects of routine environmental variability on aquatic animals are compounded by stochastic events like hurricanes and severe fires. The aquatic animals have a variety of means by which to cope with environmental variability. These include movements among habitats to find breeding sites or refuge from drying, resting stages to survive drought, reproductive adaptations, etc. Human-induced changes have affected the natural variability of environmental conditions by altering the seasonality and areal extent of flooding in the wetlands, by drainage or extra-inundation of neighboring marsh systems, and by addition of excess chemicals from urban and agricultural areas (Gunderson and Loftus 1993). Aquatic communities respond to human-induced changes through loss of diversity, changes in composition and abundance, and probably through alterations in energy-flow pathways (Loftus et al. 1990). Some of the changes are subtle and difficult to detect in the early stages until they are manifested in obvious collapses of native communities and natural processes. A good example is the recent finding of mercury at dangerous levels in the fishes of this region and their predators (Loftus and Bass 1992). As human population pressures increase on the wetland systems, it is crucial to have adequate information to distinguish natural variations in environmental factors and community responses from those produced by human interference. Changes that reduce the population sizes, community composition, or availability of aquatic animals will affect all facets of the ecology of these wetlands.

To insure healthy aquatic ecosystems and to be able to detect natural or human-induced changes in those systems, baseline data on the constituent aquatic communities and their ecology are needed. Because the Everglades/Big Cypress system is composed mainly of aquatic habitats, knowledge about fishes is especially important. Yet fishes are difficult to study, because of sampling and transportation logistics, and wide, natural variability in populations and environmental conditions. Baseline data collections to document fish community composition, ecology, and dynamics have not always received emphasis or support because they are expensive and long-term, and because

fishes are not as charismatic as other fauna. Yet, the fishes support many of the predatory animals, especially alligators and wading birds, which characterize the Everglades marsh; fishes testify to the health of the wetland and attract human visitors, from fishermen to naturalists. It is important to catalog the fish faunas, and to understand their productivity and availability to predators under natural conditions, so that predator populations will be maintained.

Because of the hydrological changes wrought by drainage and impoundment, and the loss of spatial extent and functioning of former wetlands to development (Gunderson and Loftus 1993), there can be little doubt that fish standing crops and overall numbers have declined. Those changes to the original system have also altered the timing and the areas of fish availability to predators. Indirectly, the fishes have been detrimentally impacted by hydropattern alteration through effects on alligators, which prey on fishes and provide them dry-season refuge in their ponds, and through impacts on wading birds, which transfer energy from the marshes to other habitats through predation. Non-native fishes have colonized natural and disturbed habitats during the past three decades. The climate and geography of the sub-region make it conducive to non-native animal invasions (Loftus and Kushlan 1987). The rate by which fishes have been introduced into area waters has increased since the mid-1970's. Documented impacts on native animals include predation, nest-site competition, and habitat disturbance (Loftus 1988). The eventual extent of invasion, geographically and numerically, is uncertain. It seems likely that more species will invade, and that all will extend their ranges within the sub-region, with unknown ecological consequences. Non-native fishes may divert food-web energy into biomass unavailable to top-level predators.

What Has Been Done: The first studies of southern Florida freshwater fishes were done by the University of Miami in the early 1950's-1960's (Hunt 1952, Reark 1961). Those mostly unpublished studies provided some data on species composition, diets, standing stocks, and habitat use. From 1965 to 1972, the USGS was contracted to collect data on fish community composition and population variability in Shark Slough (Kolipinski and Higer 1969). Those data were published later (Kushlan 1980). In 1976, the Research Division of Everglades National Park began a long-term commitment to studying the aquatic ecosystem. The inventory data for fishes in the southern Everglades are current and accurate. Some level of information exists for fish habitat usage, food habits, reproduction, standing stock dynamics, and relation to hydropattern; however, many of those studies were preliminary rather than definitive in nature.

Current Research

Recent investigations include a study of the effects of hydroperiod alteration on marsh food webs (Loftus et al. 1990), and the study of the effects of Hurricane Andrew on the community (Roman et al. 1994). A long-term study of the effects of natural and altered hydropattern on aquatic animal community structure and standing stocks in several Everglades marshes is continuing and has been expanded. In the Big Cypress region, little work has been done with fishes. Kushlan (1974) reported the responses of fishes to dry-season conditions in an alligator pond. There are distributional data for native and exotic fishes from U.S. 41 and southward in the Preserve (Loftus and Kushlan 1987); limited, quantitative community data exist from the Corkscrew Swamp (Carlson and Duever 1977) and the southern Big Cypress region (Carter et al. 1973). Since 1990, the Florida Game and Fresh Water Fish Commission has sampled game fishes in this sub-region for mercury concentrations.

Freshwater fish and aquatic invertebrates are sampled regularly in Shark River Slough. Throw traps are used at nine sites five times yearly, continuing a data base begun in 1977. Electrofishing in five alligator ponds is done twice a year and, for qualitative purposes, pull traps continue to be employed to sample aquatic animals in the slough.

Critical Data Needs and Approaches

1. Within the sub-region, data on **fish community composition and dynamics** in undersampled habitats and landscape areas should be collected to understand the functioning and the organization of communities. Efforts should be focused on the Big Cypress Swamp, the freshwater-mangrove interface, and short-hydroperiod peripheral wetlands. Methods and sampling frequency should match the current collection program in Everglades National Park for comparability. The sub-region-wide effort should be supported for a minimum of five years to try to encompass a range of climatic conditions in the data base. Linkages between the data collection in this sub-region and adjacent regions should be made to provide system-wide monitoring of fish numbers, and to take advantage of the large, natural "experiment" to assess fish responses to conditions resulting from drainage and impoundment of waters in various compartments of the Everglades.

2. **Life-history parameters** of important fish species remain to be studied at sites that represent a range of sub-region environments. Although some information on reproductive aspects of the fishes, their recruitment seasons, and age and growth have been collected, the data base is far from complete. The kinds of work needed to accomplish this include a study of fish otoliths for daily growth increments to calculate age at size as well as to estimate growth rates under different seasons and habitats. A study of fish fecundity and related parameters is needed to estimate reproductive potential. These studies, in combination with the data from #1 above, would provide the information needed to construct life tables for the species under different conditions in the Everglades.

3. **Food webs** involving the fishes of the sub-region are poorly understood, but unraveling the connections and calculating the flow networks will be valuable. These data are obtained by direct observations of fish gut contents and feeding behaviors, and indirectly can be discerned by stable isotope analysis of fish tissues to determine which plant groups are the primary carbon sources for fishes in different habitats. The data are also useful in predicting the passage of biocontaminants through the system.

4. Continued sampling of aquatic habitats in the sub-region is needed to assess ranges, composition, and abundance of the **non-native fishes**. Some of this information will be gathered if Study #1 is funded. However, periodic and well-planned monitoring of habitats not covered by the fish sampling study, in addition to interaction studies discussed under Mesocosm Studies, will be required to fully understand the non-native fish problem. To try to cope with this problem, an investigation of potential control methods is needed. Control possibilities will have to be tied in to life-history research to identify vulnerable life stages or behaviors that can be targeted.

5. **Biocontaminant studies** of the fishes have not been done in a systematic manner. Screening for contaminants should be funded on a periodic basis to detect potential problems. Fishes are integrators of contaminants in their environment, so are effective, early-warning species for contaminant detection. The mercury issue is a currently recognized problem with implications for the entire system. Studies of mercury mobilization, transfer, and direct effects on fish health and behavior are needed.

6. Attempts to build credible and useful **simulation models** for the fishes in this sub-region are underway, but are limited by the lack of important data. The studies needed to provide those data include those mentioned above (reproduction, recruitment, age, growth, and mortality). There are several landscape-based studies also required to build these models. One would involve the dynamics of fish movements related to the seasonal fluctuations in water level, including composition and numbers in refugia during the dry season, the distances and rates of seasonal dispersal movements, etc. Although some information may be gathered through traditional mark-recapture study, the small sizes of the fishes and the vast area of the sub-region preclude that approach. An indirect way to investigate these questions is by using genetic markers to identify population structure in the fish populations, which may provide a gauge of the degree of mixing of populations via dispersal movements.

7. **Trophic-network modeling** of the fish community provides a "circuit diagram" of the pathways and amounts of energy flow and compartmentalization. This modeling approach is a useful diagnostic tool in system study. It also has value in tracking the movement of contaminants through the food web. There is a possibility of integrating this kind of model with the simulation models to have a dynamic picture of how changes in the environment translate into community changes and thence into food web shifts. The construction of a trophic network requires better data for the fish-prey population biomass and cycling.

8. Some studies needed to understand the fish community are difficult to carry out in the field, yet require more space than the confines of laboratory aquaria. **An experimental mesocosm** has been proposed for construction in Everglades National Park to meet the needs of certain kinds of investigations. If funded, this facility will be useful in answering questions about predator-prey, competitive, and indirect interactions. The mesocosm is suited to address questions about the role of nutrient inputs into the Everglades in causing shifts in marsh food webs. The mesocosm will provide the opportunity to examine introduced/native fish interactions, and to test potential control methods.

MAJOR ISSUE: Declines in aquatic invertebrates.

Background

Freshwater invertebrates are important and abundant animals in the Everglades/Big Cypress system and, as such, are critical in the transfer of energy through the system. This is particularly true in the shorter hydroperiod wetlands of the sub-region. These animals operate at several trophic levels in the wetlands, as primary consumers of plant material and detritus to carnivores and scavengers. Some species, such as the crayfish and the apple snail, are major prey for fishes and other predatory species, including characteristic or endangered animals like the Snail Kite, White Ibis, and American Alligator. Factors that influence invertebrate numbers, biomass, and composition therefore affect energy flow through the wetlands. The ecology and life histories of the invertebrates are intimately tied to the hydrology of the marsh, which is determined mainly by rainfall, but increasingly by water-management practices. Water management through flood releases, diversions, and impoundment of water appears to adversely affect aquatic invertebrate stocks and their distributions. Such direct effects of water management are compounded by the subtle impacts of drying on marsh ecology, in particular the reduction of wetland productivity. Disturbances, such as hurricanes and droughts, result in dramatically reduced standing stocks, sometimes for years following the event.

What Has Been Done: Two of the first studies to report invertebrate data from the sub-region were done by the University of Miami (Hunt 1952, Reark 1961). From 1965 to 1972, the USGS collected data on the densities and biomass of some macroinvertebrate species in Shark Slough. Those data were published later in a series of papers (Kushlan 1975, Kushlan and Kushlan 1979, 1980b). In 1976, ENP began to support studies of habitat use, reproductive seasonality, and standing stocks,for selected macroinvertebrates, as part of fish research in the Everglades. Baseline compositional data for certain groups of aquatic insects and snails published in statewide treatments are applicable to the sub-region. Recent investigations have provided the first information on micro-invertebrate composition and dynamics (Loftus et al. 1990, Reid 1992). For most freshwater invertebrates, baseline data on population levels and dynamics are limited to only the most abundant groups (cladocerans, copepods, and some aquatic insects), and apply to only one habitat type. Data for apple snails (*Pomacea paludosa*) (Kushlan 1975), the crayfish (*Procambarus alleni*) (Kushlan and Kushlan 1979), and the freshwater prawn (*Palaemonetes paludosus*) (Kushlan and Kushlan 1980b) have been published. Non-native invertebrates are less well-inventoried in the sub-region because of sampling and identification difficulties; data on composition, distribution, and habitat usage are available for some taxa of molluscs and dragonflies.

Description of Research Needed: Baseline inventories of the invertebrate communities in representative habitats should be done to estimate species richness and to catalogue the fauna. Too little is known about most invertebrate taxa in the Park to determine whether threatened and endangered species occur. Little work has been done to examine aspects of animal behavior, productivity, and pathways of energy flow through the system as related to hydropattern and disturbance. This is unfortunate because of the ecological roles of invertebrates in system food webs. Basic information is also unavailable to describe the ecological processes that regulate and structure the invertebrate communities in different habitats. That information is critical to the simulation modeling process used to evaluate ecological impacts, and in the selection of alternative management options to restore the system. Current needs include:

- Complete inventories of native and introduced invertebrate groups by habitat;
- Life history studies of important invertebrate species;
- Habitat use, movements and dispersal among habitats with changing environmental conditions and seasons;
- Documentation of the ecology and composition of invertebrates that permanently occupy, or show dry-season use of, subterranean aquatic habitats, and their ecological interactions with surface-water environments;
- Analyses of aquatic food-web pathways and trophic relationships involving invertebrates;
- Determinations of environmental conditions that make sufficient quantities of invertebrate prey available to support successful nesting by wading birds;
- Effects of contaminants, especially mercury, on the population dynamics and health of invertebrates.

Most of the research data for invertebrates in this sub-region has been collected from the Shark River Slough in Everglades National Park. A small amount of density and biomass information, mainly for larger macroinvertebrates, has been collected from Taylor Slough, the Rocky Glades, and at the marsh-mangrove interface. There are almost no quantitative data for western Shark River Slough or the Big Cypress Swamp. A very limited data base on reproduction, diet, size frequencies, growth, and other important life-history characteristics exists for a small study area of long-hydroperiod marsh in central Shark River Slough. Any invertebrate study should attempt to collect data in representative habitats across the sub-region, in light of the poor state of knowledge.

Current Research

Other than the sampling described under fishes (above), no other research or monitoring in occurring.

Critical Questions and Research Approaches

1. Throughout the sub-region, data on **invertebrate community composition and dynamics** should be collected to understand the functioning and the organization of communities, especially in short-hydroperiod peripheral wetlands where crayfish appear to be the dominant aquatic species. Methods and sampling frequency should match the current collection program in Everglades National Park for comparability. The sub-region-wide effort should be supported for a minimum of three years to try to encompass a range of climatic conditions in the data base and to use the large, natural "experiment" of the divided Everglades to assess responses to environmental conditions. These study elements would address several objectives, and would provide data for model building, calibration, and validation.

2. **Life-history parameters** of important macroinvertebrate species should be studied at sites that represent a range of sub-region environments. Although information on reproductive aspects of some of the species, their

recruitment seasons, and growth has been collected, the data base is far from complete. These data are needed to meet several objectives. The kinds of work needed to accomplish this include a study of size frequencies and markers to estimate growth rates under different seasons and habitats. A study of fecundity and related parameters is needed to estimate reproductive potential. These studies, in combination with the data from #1 above, would provide the information needed to construct life tables for the species under different conditions in the sub-region.

3. **Food webs** involving the invertebrates of the sub-region are poorly understood, but unraveling the connections and calculating the flow networks will be valuable in meeting all of the Objectives. These data are obtained by direct observations of gut contents and feeding behaviors, and indirectly can be discerned by stable isotope analysis of invertebrate tissues to determine which plant groups are their primary carbon sources. The data are also useful in predicting the passage of biocontaminants through the system.

4. Continued sampling of aquatic habitats in the sub-region is needed to assess ranges, composition, and abundance of the **non-native invertebrates**. Some of this information will be gathered if Study #1 is funded. However, periodic and well-planned monitoring of habitats not covered by the field sampling study, in addition to interaction studies discussed under Mesocosm Studies, will be required to fully understand the non-native invertebrate situation. Control possibilities will have to be tied in to life-history research to identify vulnerable life stages or behaviors that can be targeted.

5. **Biocontaminant studies** of the invertebrates have not been funded. Screening for contaminants is needed on a periodic basis to detect potential problems. Like fishes, the invertebrates are integrators of contaminants in their environment, so are effective early indicators of contaminants. The mercury issue is a currently recognized problem with implications for the entire system. Studies of mercury mobilization, transfer, and direct effects on the invertebrates are needed to meet Objective E.

6. **Simulation models** for the invertebrates in this sub-region are presently being constructed, but are hampered by the lack of data. The studies needed to provide those data include those mentioned above (reproduction, recruitment, age, growth, and mortality). There are several landscape-based studies also required to build these models. One would involve the dynamics of movements related to the seasonal fluctuations in water level, including composition and numbers in refugia during the dry season, diapausing ability, the distances and rates of seasonal dispersal movements, etc. Although some information for larger invertebrates may be gathered through traditional mark-recapture study, that approach is infeasible for most. An indirect way to investigate these questions is by using genetic markers to identify population structure in the populations. That technique may help determine the amount of mixing of populations as relates to dispersal movements.

7. **Trophic-network modeling** of the invertebrate community provides a diagnostic tool to discern the pathways and amounts of energy flow and compartmentalization. It also has value in tracking the movement of contaminants through the food web. There is a possibility of integrating this kind of model with the simulation models to have a dynamic picture of how changes in the environment translate into community changes, and thence into food web shifts. The construction of a trophic network requires better data for invertebrate community biomass and cycling.

8. Some studies of the invertebrate community are difficult to carry out in the field, yet require more space than the confines of laboratory aquaria. **An experimental mesocosm** has been proposed to be built in Everglades National Park to perform certain kinds of investigations. If funded, this facility will be useful in answering questions about predator-prey, competitive, and indirect interactions. The mesocosm is suited to address questions about the role of nutrient inputs into the Everglades in causing shifts in marsh food webs through effects on the invertebrate community. The mesocosm will also provide the opportunity to test potential control methods.

MAJOR ISSUE: Fluctuations in aquatic herpetofauna communities.

Background

Members of the aquatic herpetofauna are often very abundant components of the ecosystems in this sub-region. In particular, the amphibians may be found over the widest range of habitats, from temporary pools formed in the wet season to the deepest, most permanent sloughs and strands. Salamanders, such as the peninsula newt, dwarf siren, and amphiuma, are predators on small crustaceans, crayfish, and fishes. During their development, the frogs and toads switch roles from being mainly herbivorous as tadpoles, becoming predators on insects, crustaceans, and other animals as adults. The aquatic snakes, while never as abundant as the amphibians, are important predators on a variety of animals in the aquatic system. Several species of turtles are locally abundant in deeper, more permanent waters of the sub-region. All of the aquatic herpetofaunal members are prey for larger Everglades predatory species - even alligators are taken as prey by large fishes and wading birds when newly hatched. Several species, especially the pig frog, alligator, and Florida softshell turtle, are harvested for food by humans. Those species and others collected for the pet trade provide some economic return in the ecosystem.

The first scientific reports of the amphibians and reptiles of southern Florida were compositional and distributional descriptions published in the early decades of this century (summarized by Steiner and Loftus in press). Carr (1940) provided a relatively complete record of the distribution of reptiles and amphibians in southern Florida, listing records for 162 species and subspecies for the entire state by county. His accounts presented general ecological data on habits, habitat, abundance, feeding, and reproduction. Carr (1940) documented nearly all of the presently known native species from southern Florida. The study by Duellman and Schwartz (1958) stands as the most comprehensive work on the herpetofauna of southern Florida. The monograph included detailed data on taxonomy, general ecology, and distribution for 85 species of reptiles and amphibians, including data from several collecting localities within Everglades National Park and the Big Cypress region. Data on the marsh herpetofauna have been collected during fish studies in the park, but basic biological/ecological data on size-frequency, food habits, and reproduction for the marsh herpetofauna have not been produced. An inventory for the park is in press; some data are available for the Big Cypress Swamp (Duever et al. 1979). A monograph on the pig frog (*Rana grylio*), an ecologically and economically important amphibian, is applicable to the sub-region, though based on research from the northern Everglades (Ligas 1960).

About a half dozen of the 25 established, introduced species of reptiles and amphibians found in southern Florida (Wilson and Porras, 71) are presently known to be established within the sub-region boundaries. Several additional species have been taken there, but probably have not established viable populations. Future colonizations by additional species are likely. During winter and during dry seasons, massive mortality of the aquatic herpetofauna often occurs along area roadways as the animals move in search of water, warmth, or nesting sites. Only one study of the extent of vehicular mortality on the herpetofauna is available.

Most of the research information available for fishes in this sub-region has been collected from the Everglades National Park, in central Shark River Slough or in the Long Pine Key-Taylor Slough area. Much smaller data sets exist for the Rocky Glades area and at the marsh-mangrove interface. There are few data for western Shark River Slough or the Big Cypress Swamp. Data on reproduction, food habits, age and growth, and other important life-history characteristics have been collected for only a few species, mainly from a small study area around Taylor Slough-Long Pine Key.

Critical Questions and Research Approaches

1. Throughout the sub-region, data on **herpetofaunal community composition and dynamics** should be collected to understand the functioning and the organization of communities. Work should be concentrated in short-

hydroperiod, peripheral wetlands where frogs and toads appear to be important aquatic species, and in the long hydroperiod marshes and strands. The data should be related to seasonal and annual fluctuations in the environment of sub-regional habitats through collections across several years. These collections will also monitor the status and habitat use of non-native species.

2. **Life-history parameters** of important amphibian and reptile species should be studied at sites that represent a range of sub-region environments. Little information on reproductive aspects, their recruitment seasons, and growth has been collected. These data are needed to meet several objectives. The kinds of work needed to accomplish this include a study of size frequencies and markers to estimate growth rates under different seasons and habitats. A study of fecundity and related parameters is needed to estimate reproductive potential. These studies, in combination with the data from #1 above, would provide the information needed to construct life tables for the species under different conditions in the sub-region.

3. **Food webs** involving the herpetofauna of the sub-region are poorly understood, but unraveling the connections and calculating the flow networks will be valuable in meeting all of the Objectives. These data are obtained by direct observations of gut contents and feeding behaviors, and indirectly can be discerned by stable isotope analysis of the animal tissues to determine their primary carbon sources and energy pathways in different habitats. The data are also useful in predicting the passage of biocontaminants through the system.

4. **Biocontaminant studies** of most members of the aquatic herpetofauna have not been funded. Screening for contaminants is needed on a periodic basis to detect potential problems. Because many of these species are high-level predators in the aquatic systems of the sub-region, they can serve as early indicators of bioaccumulatory contaminants. The mercury issue is a currently recognized problem with implications for the entire system. Studies of mercury mobilization, transfer, and direct effects on the reptiles and amphibians are needed to understand the potential risks to human consumers and to the ecosystem.

5. Some studies of community interactions and responses are difficult to carry out in the field, yet require more space than the confines of laboratory aquaria. **An experimental mesocosm** has been proposed to be built in Everglades National Park to perform certain kinds of investigations. If funded, this facility will be useful in answering questions about predator-prey, competitive, and indirect interactions. The mesocosm is suited to address questions about the repercussions of harvesting of herpetofauna on their predators and prey. The mesocosm will also provide the opportunity to test other biotic interaction hypotheses to clarify the roles of these species in the system. Those kinds of data are integral to the construction of credible simulation models for the aquatic system.

MAJOR ISSUE: Declines in mammals dependent on freshwater marsh habitat.

Background

Although no empirical data exist that would document population trends by most species of mammals occurring in the Everglades/Big Cypress basins, and which are not listed as endangered or threatened, it is widely speculated that several species which are dependent on freshwater marsh habitats have substantially declined due to water management practices. Two species of principal concern are the round-tailed muskrat and the river otter. Other, more upland species such as the three native squirrels (Gray, Fox, and Southern flying) and the Black Bear have become greatly reduced in numbers and range. In addition, the ecological consequences of an expanding population of introduced feral pigs have not been measured.

The species of mammals that have been most intensively studied in the Everglades/Big Cypress basins are the Florida panther (for example, see McBride 1985, Belden 1988, Smith and Bass 1994) and White-tailed Deer (Boulay

1992, Sargent 1992, Zultowsky 1992, Miller 1993, Smith and Bass 1994). More limited, local studies and censuses have been conducted for the Fox Squirrel (Williams and Humphrey 1979, Jodice and Humphrey 1992, Jodice 1993), the Round-tailed muskrat (Tilmant 1975), the Everglades mink (Smith 1980, Humphrey and Zinn 1982) and the Black Bear (Brady and Maehr 1985).

With the exception of the well-studied panther and deer, we have only limited information on population trends, regional distribution patterns, or on the biology or population ecology of most Everglades/Big Cypress mammals. The basic need is for the development of census protocols for a number of these species, the initiation of censuses based on these protocols, and for a series of field ecology studies for species suspected of having declined and/or been adversely affected by management practices. Recently initiated efforts to design models for predicting population responses by panther and deer to management alternatives must receive a high priority (Fleming, pers. comm.).

Spatial aspects: Collectively these species of mammals occur throughout the Everglades/Big Cypress basins. The current uncertainties regarding the status of each, or the nature of limiting factors or adverse management impacts, argues that no geographical limitations be placed on initial censuses or studies.

Current Research

Florida Panther and White-tailed Deer continue to be studied and monitored in the Big Cypress region, through projects coordinated by the Game and Fresh Water Fish Commission and Fish and Wildlife Service for the panther, and Dr. Ron Labisky (University of Florida) and the National Park Service for the deer. The Systematic Reconnaissance Flights at Everglades National Park include a dry season and wet season census of deer in Shark Slough. A very small study of food habits by feral pigs is being coordinated through Everglades National Park. Development of ATLSS models for panther and deer is continuing, under the direction of Dr. Lou Gross, University of Tennessee, and Dr. Michael Huston, Oak Ridge National Laboratory, respectively. No other mammal projects are currently active for these sub-regions.

Critical Questions and Research Approaches

1. Develop and implement long-term census program for Marsh Rabbit, Round-tailed muskrat, River Otter (and others?).

2. Conduct base-line censuses for other species suspected of having declined in numbers or had a reduction in range (squirrel species, etc.).

3. Establish a study to determine the impacts of the increase and range expansion by feral pigs.

4. Continue the development and evaluation of panther and deer models for the freshwater basins of the southern Everglades/Big Cypress.

MAJOR ISSUE: Massive declines in wading birds throughout the region.

Background

The total number of wading birds nesting in these two sub-regions, for the five species that numerically dominated the traditional, Everglades colonies (Great Egret, Snowy Egret, Tricolored Heron, White Ibis, Wood Stork), has declined by more than 95% from the peak estimates of nesting birds during the 1930s. Peak annual estimates of

nesting waders in the region of these traditional colonies was 180,000-245,000 birds during the 1930s compared to peak numbers of 5,700-7,500 nesting birds in the decade between 1984-1993 (Ogden 1994).

A good case has been made that wading birds are among the most important vertebrate indicators of ecological trends in the Everglades basin (Kushlan 1993, Ogden 1993). The current wading bird database for the southern Everglades contains considerable information on colony locations, numbers and species of nesting birds, timing and success of colonies, basic reproductive biology and food habits for the principal species, foraging patterns around colonies, regional foraging patterns of total wader populations (Systematic Reconnaissance Flights), long-term population trends. These data have shown that most wading birds in the pre-drainage Everglades nested in the extreme southern portion of the basin, with the larger, traditional colonies located either along the mangrove/freshwater marsh interface at the lower end of the Shark Slough, or within the belt of mangrove forest downstream from the Big Cypress and southern Everglades systems. A current hypothesis is that the combination of mainland estuaries and adjacent freshwater marshes in the far southern Everglades provided a relatively greater range of foraging habitat conditions and higher levels of primary/secondary production than did other regions in the Everglades basin (Bancroft et al. 1994, Frederick and Spalding 1994). Wading birds have responded to unnatural alterations in hydropatterns by (1) reducing the number of birds attempting to nest, (2) relocating colonies, (3) changing the timing of nesting, and (4) having fewer years of successful nesting. Relocation of nesting has occurred primarily by birds moving away from the traditional colony sites to the Water Conservation Areas; the affected birds have for the most part been the smaller species of waders that have relatively short foraging ranges around a colony, and thus the pattern of colony relocations may be a response to changes in locations within the Everglades basin of the longer hydroperiod pools. Changes in timing of nesting, primarily by storks, appears to be a response to degradation of early dry season foraging habitat in the mainland estuaries. Changes in location and timing of nesting may be the major causes for the great reductions in nesting effort and colony success rates among all species.

At this point, a substantial improvement in our understanding of the relationships between the decline in wading birds and the changes in hydropatterns in the southern Everglades that have resulted from water management practices will require increased research efforts into (1) the dynamics of the prey populations for these birds, and (2) the specific foraging strategies and patterns of wading birds that are associated with successful nesting. Wading birds feed primarily on small fishes and the larger aquatic invertebrates. Production and survival of these prey species in each of the major habitats/communities of the Everglades, as affected by water quantity and quality parameters, is currently being measured only for deep water, marsh sloughs and estuarine flats and creeks (Loftus and Eklund 1994, Lorenz 1993). The water management strategies that will recover these prey populations, and the ecological processes that must be understood as a framework for designing these management strategies, are yet to be determined.

Research on wading bird feeding patterns related to colony success patterns has been reported by Frohring (1988), and is currently being investigated by Frederick (1993). P. Frederick and M. Spalding (pers. comm.) also have initiated a study of Great Egret reproductive performance related to mercury levels in tissue, and have developed a proposal for a study of the ecology and impacts of Eustrongylides on wading bird colony success rates. A series of inter-active models designed to predict wood stork/wading bird responses to alternative management plans is currently being developed by a coordinated program between Everglades National Park, the Florida office of the N.B.S., and the University of Tennessee (Fleming pers. comm.). These models have the potential for being selected as a primary tool for evaluating alternative redesign proposals for the feasibility phase of the C.S.F. Restudy.

Spatial aspects: It has been proposed that the pre-drainage Everglades was able to sustain large numbers of wading birds because the region's large spatial extent, habitat heterogeneity, and it's dynamic hydrological patterns combined to create many optional foraging sites under a wide range of rainfall patterns. Thus the highly mobile waders could adjust the location and timing of nesting between years, in response to seasonal and annual differences

in hydropatterns. Research and management questions raised by this issue require a broad scale assessment, both in terms of geographical extent and for a wide range of communities, of the dynamics of prey populations related to hydrological variables.

Current Research

Wading bird nesting colonies continue to be minimally censused in Sub-region 6, but not in 7. Total wading bird numbers are measured annually, primarily during 6 dry season months and a single wet season month, by the Systematic Reconnaissance Flights. Dr. Peter Frederick is continuing a study of wading bird foraging behavior related to colony dynamics, in the Water Conservation Areas and in the Shark Slough of Sub-region 6. Development of the ATLSS wading bird models is being coordinated by Dr. W. F. Wolff, Oak Ridge National Laboratory and University of Tennessee.

Critical Questions and Research Approaches

1. Determine the relationships between the characteristics of small fish/aquatic macroinvertebrate populations and water quantity and quality patterns (including salinity), for major wading bird foraging habitats. Priority study sites should include most mainland, estuarine habitats (tidal and non-tidal creeks, brackish marshes, marl flats, etc.), along with the shorter hydroperiod, freshwater marl prairies and the pond cypress/bald cypress mosaics. Specific questions that should be answered include: Are mainland estuarine habitats potentially more productive of these prey species, and capable of creating higher concentrations, than freshwater habitats, and if so, how and by what processes?

2. Expand and standardize wading bird colony censuses, to include all of Sub-regions 6 and 7. Currently the aerial censuses of colonies do not cover the Big Cypress sub-region, and the census protocol for Everglades National Park differs from the colony census protocol used in the Water Conservation Areas and Lake Okeechobee. Regional response patterns by wading birds to hydrological conditions will not be fully known until a more comprehensive wading bird colony census is employed. The wading bird colony record is the strongest vertebrate database from the Everglades basin, and its value for showing temporal and spatial responses to management practices is increasingly appreciated.

3. Examine the Systematic Reconnaissance Flight database (1985-1994) to determine whether regional foraging patterns by wading birds provide insights into the dynamics of colony patterns, specifically the species composition, number of nesting birds, and the location and timing of nesting. If we can show clear linkages between regional hydropatterns, wading bird foraging patterns and colony patterns, these relationships can have strong management applications during the implementation and refinement of experimental programs for Everglades restoration.

4. Determine the ecology of the avian nematode parasite, Eustrongylides ignotus. Key questions pertain to possible relationships between this nematode and waters with high nutrient loads, and to the potential for this nematode to cause high rates of mortality among nestling wading birds. One colony in Everglades National Park in 1988 (Rodgers River Bay) had an 80% infestation rate among nestling herons and egrets.

5. Continue on-the-ground studies of colony nesting success patterns, particularly to measure relationships between hydrological/climatological parameters and reproductive performance.

6. Determine relationships between mercury contamination in the freshwater Everglades/Big Cypress and wading bird reproductive dynamics.

7. Continue development and refinement of regional, inter-active wading bird models; evaluate our needs for an array of wading bird models, for dealing with future restoration projects which are expected to occur at a range of spatial scales.

MAJOR ISSUE: Declines in water birds (all species other than wading birds).

Background

Long-term, qualitative observations in the southern Everglades suggests that most of the formerly common water birds (Pied-billed Grebe, Anhinga, Mottled Duck and wintering waterfowl in general, Coot, Limpkin, etc.) have substantially declined in numbers in the southern Everglades during the past several decades. Relatively little in the way of quantitative information exists for any of these species, which can be used to either substantiate or refute these observations.

The common perception is that all species of waterbirds that were once commonly associated with the freshwater Everglades communities have become numerically much less common, and less widely distributed in the system. Although these perceptions are poorly documented, the very limited amount of quantitative data that do exist support the perceptions for a few species. A waterfowl and coot census in Everglades National Park in the winter of 1977-1978 revealed approximately 70,000 birds (about 50% coots) along a standardized census route (Kushlan et al. 1982). Similar annual censuses along the same route between 1991 and 1993 produced an annual mean of 530 birds (<20% coots; O. Bass, pers. comm.). Aerial censuses of West Lake, ENP, during the late 1960s revealed maximum wintering populations of 50,000 coots; less than 500 coots have wintered on the same lake since 1988 (J. Ogden, pers. comm.). Almost certainly, across-the-board declines by a number of taxonomically and ecologically dissimilar waterbirds has occurred for a complex array of reasons, probably including (1) outright loss of wetlands, (2) reductions in food availability in remaining wetlands caused by altered hydropatterns, (3) reductions in food caused by increases in salinity in mainland estuarine lakes, and (4) problems for migratory species occurring outside of the Everglades.

The population trends and baseline population measures need to be determined for these species by means of systematic reviews of historical data and the implementation of censuses for select species and habitats.

Spatial aspects: These species, collectively, occur in a broad range of freshwater and estuarine habitats. Perhaps characteristic of many wetland species of birds, several of these species are known to make, or are suspected of making, sizable range shifts in response to seasonal and annual differences in hydropatterns. Their food habits are just as diverse, and include submerged vegetation (coot, some ducks), aquatic insects (gallinules), apple snails (limpkin), and fishes (grebe, anhinga).

Current Research

Except for a single, mid-winter census of waterfowl in Sub-region 6, and on-going research on the endangered Snail Kite (see Endangered species), no studies of these species are currently active.

Critical Questions and Research Approaches

Research objectives: The priority is to develop and implement census protocols for those species not previously censused (grebe, anhinga, limpkin), and to review established census protocols for other species (waterfowl, coot). Censusing of several of these species should become a part of a much more comprehensive, regional census program

for the Everglades/Big Cypress basins, designed to measure species responses across a wide range of habitats and for representative species from the full spectrum of food habits guilds.

MAJOR ISSUE: Decline in numbers and shift in center of distribution of the American alligator.

Background

The American Alligator is one of the most ecologically significant of the larger vertebrates in the Everglades and Big Cypress basins. As such, a properly designed monitoring program for this animal can serve both to define the nature of ecological problems in these systems, and as a measure of progress towards achievement of restoration goals. Ecological studies of the alligator in Everglades National Park have shown that recent water management strategies have caused reduced reproductive effort, increased frequencies of nest flooding, and increased rates of juvenile mortality (Kushlan and Jacobsen 1990, Fleming 1991, G. Dalrymple pers. comm.). While these recent studies have produced valuable information on southern Everglades alligators, considerable additional data is required for improving alligator population models and for strengthening the utility of this species as an indicator of ecosystem conditions.

American Alligators in the southern Everglades have shown large changes in numbers and distribution in response to the shifting influences of over-harvesting, protection and habitat alterations (Craighead 1968, Mazzotti and Brandt 1994). Perhaps the most important ecological change has been the substantial reduction of the population in the higher elevation, freshwater marshes flanking the deeper sloughs, and in the inner, more freshwater portions of the mainland mangrove regions. Craighead (1968) suggested that alligators declined in these areas due to overdrainage in the former, and increased salinities in the latter. Conversely, numbers of alligators have increased in the deeper, central sloughs, in areas that apparently were too deeply flooded in the pre-drainage Everglades to support a large nesting population. The central Shark Slough now supports the highest densities of nesting alligators in Everglades National Park (Fleming 1991).

Fleming (1991) has shown that the number of adult female alligators that initiated nesting in Shark Slough was inversely related to the areal extent of surface water remaining in the study area at the end of each dry season. Thus, the increased frequency of major drydown events in Shark Slough, as a consequence of recent water management practices, has become the single most important factor responsible for reduced production by alligators in the primary habitat for this population (Fleming pers. comm.).

The importance of the alligator as an indicator of ecosystem conditions requires that additional research and monitoring be conducted, and that one or more models of alligator population dynamics related to hydrological patterns be developed and evaluated. We know relatively much less of alligator reproductive ecology, annual habitat patterns and demography in cypress, mangrove, and the marl soils Everglades communities than is known for the Shark Slough communities. In all communities, the empirical databases must be enlarged for all of these parameters, but especially for relationships between reproductive performance, population structure and distribution, and hydrological/contaminant (mercury) parameters. An improved monitoring capability will require the development of refined census protocols, most importantly for cypress and mangrove communities.

Spatial aspects: Research and monitoring for alligators in the Everglades/Big Cypress systems should be conducted in large study areas representative of the major community types in these regions. The Shark Slough study area (Fleming 1991) includes approximately 110,400 ha of prairie and slough marshes.

Current Research

The program of Systematic Reconnaissance Flights to measure alligator nesting effort and success was expanded in 1994 to cover both Shark and Taylor sloughs in Sub-region 6. Development of an ATLSS model for the alligator is being coordinated by Dr. W.F. Wolff, Oak Ridge National Laboratory and University of Tennessee.

Critical Questions and Research Approaches

1. Develop protocols and implement long-term monitoring for measuring alligator nesting patterns related to hydrological conditions, for cypress, mangrove, and marl soils Everglades communities. Current aerial monitoring of alligator nesting performance is limited to Shark Slough and adjacent higher elevation marshes (Fleming 1991).

2. Develop protocol and implement monitoring for measuring seasonal and annual alligator population structure (age and sex classes) related to community types. Census techniques for measuring the population structure of alligators in the canal along the Shark Valley observation tower road have previously been evaluated by G. Dalrymple (pers. comm.).

3. Fleming (1991) has recommended studies of:
   a) daily and seasonal activity patterns, movements, activity ranges, and habitat preferences by sex and age classes;
   b) seasonal food habits by sex and age classes; and
   c) sex and age specific growth and survival rates.

4. Continue the development, evaluation and refinement of alligator population model(s).

MAJOR ISSUE: The continuing, possibly accelerating, loss of species from the upland communities of Sub-regions 6/7 and the Florida Keys.

Background

The thinking and planning about restoration of the Everglades focused, quite understandably, on the expansive wetlands. The fact that upland biotic communities are an integral part of the Southern Everglades ecosystem has often been entirely overlooked or dismissed with token comment. Some points that seem to be even less generally appreciated are: 1) The fragmented uplands at the southern extremities of the coast ridges in Sub-regions 6/7 and the Florida Keys harbor most of the biological endemism that exists in the region's terrestrial communities as well as a large proportion of regional biotic diversity; 2) Within Sub-regions 6/7, economic development has eliminated 65 to 80 percent of the original upland habitats (pine forest, tropical/subtropical hardwood forest, short-hydroperiod prairie); 3) Reduced habitat area and deteriorated habitat quality have apparently resulted in an on-going loss of plant and animal species, including endemics, from the upland communities of Sub-regions 6/7; 4) Though issues of bio-diversity are frequently discussed in relation to Everglades wetlands, all of the known and imminently threatened losses of species in the present sub-regions appear to be associated with uplands. See Snyder et al. (1990) and Robertson and Frederick (1994) for recent reviews.

The disappearance from southern Florida uplands of bird species that had formerly nested was noted as early as the 1950s. See reference cited in Robertson (1955), Robertson and Kushlan (1974(, and the two references above. Other losses are yet to be thoroughly compiled, but data are probably available at least for vascular plants and other terrestrial vertebrates from early biological collections. Historical data on lower plants and invertebrates may not be sufficient to permit comment. Upland disturbance and development in southern Florida occurred late enough

that much of it was well-documented by aerial photography, in particular the photos taken regularly by counties and municipalities for tax purposes. This information source is still to be systematically investigated. Possible indirect human effects, as by alteration of fire regimes, will require examination of the appropriate databases. Robertson and Frederick (1994) offered a tentative review of some of the philosophical and practical problems likely to beset upland restoration efforts in southern Florida.

The principal research tasks are: 1) Characterize the temporal and spatial patterns of all documentable loss or decline of species in the uplands of Sub-regions 6/7 and the Florida Keys; 2) Determine in detail how these patterns relate to the direct and indirect effects of upland development and to possible non-anthropogenic forces; and 3) Investigate the feasibility of available means to correct, mitigate, or restore biotic losses in upland communities..

Spatial aspects: The study would propose to look intensively at past and present biotas and land-use history of upland communities in the Big Cypress are, southeastern mainland Florida, and the Florida Keys. This work probably would involve travel to major museums in the eastern and central U.S. where biological collections from relevant areas are deposited. As the research develops, it may be advisable to examine specific aspects of upland communities farther north in the Everglades system or comparable habitats south of Florida (northern Bahamas, Cuba). The latter, at least, would be supported by non-federal funding.

Current Research

Surveys of upland bird communities of Long Pine Key are being conducted. Results are being interpreted in relation to hurricane damage and potential for restoration. The work is funded out of the Hurricane Andrew research program. Similar work is focused on red-cockaded woodpeckers. Breeding colonies are under intensive observation over several or more years. Both projects are noted in the Hurricane Research Program table.

Critical Questions and Research Approaches

The objective of this study is to understand the widespread loss of bio-diversity from upland communities in southern Florida and determine whether feasible corrective measures exist.

MAJOR ISSUE: Surface water quality entering and leaving Native American lands, especially heavy metals (methylated mercury) in surface waters and sediments.

Background

The Seminole and Miccosukee Indian Tribes are federally recognized tribes. The Federal Government is the trustee of their lands and resources and the protector of their rights. Indian lands of the Miccosukee and Seminole Tribes are subjected to flows of surface water originating from upstream that are contaminated with high levels of nitrogen, phosphorous, heavy metals and other pollutants. These pollutants are generally attributed to intensive upstream agricultural development and other anthropogenic activities. This pollution has, over the years, resulted in contaminated fish and wildlife, which tribal members consume as part of their traditional subsistence hunting and fishing lifestyle. Tribal lands are being used as filters and treatment areas for polluted waters. This has resulted in conversion of wetlands to areas lacking the natural floral and faunal diversity of the past. The tribes must be provided research resources necessary for full participation in data collection and monitoring needed for planning and implementation of the restoration effort, for tribal rights protection, and for assurance of the Federal Government's responsibility to protect tribal trust resources. The research needs of both the Miccosukee Tribe and the Seminole Tribe are related to the needs of the Everglades Restoration and to the Federal Government's

responsibility to protect trust resources and tribal rights. The needs of both tribes are similar, and those following apply to both tribes.

Critical Questions and Research Approaches

1. What is the quality of water entering and leaving the reservations in relation to established federal, state, and tribal standards?

Approach: Develop automated water quality monitoring stations to monitor the entrance and exit sources of surface waters in the Big Cypress Seminole and Miccosukee Reservations; 11 sampling stations (7 on Big Cypress, 4 on Miccosukee) are required along with frequent and event-initiated sample analysis to establish baseline data and event-related data.

2. What quantities of water are entering and leaving the reservations?

Approach: Develop water quantity flow measurement stations at each water quality monitoring station.

3. What are the site-specific atmospheric conditions influencing water quality and quantity entering and leaving the reservations; what is the air quality on the reservations as it relates to deposition of pollutants?

Approach:

a) Install eight full-time meteorological monitoring stations (five on Big Cypress, three on Miccosukee) to monitor atmospheric conditions and provide data for event data correlation.

b) Provide monitoring of air and rain quality at two sites on each reservation utilizing wet/dry deposition boxes and PM10 high-volume monitors.

All data and samples from the sites will be sent to laboratories for required chemical analyses. The numerical data will be stored in a tribal data base that will be available for the overall restoration effort. The majority of physical parameters will be monitored by daily retrieval of data through radiotelemetry. A quality assurance/quality control plan will be developed for the water quality sampling process, data management, and analysis.

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SUBREGION 8:

FLORIDA BAY-FLORIDA KEYS-FLORIDA REEF TRACT-SOUTH BISCAYNE BAY AND ADJACENT COASTAL AREAS

BACKGROUND AND EXISTING CONDITION

Subregion 8 includes a diversity of marine, estuarine, fringing, and terrestrial habitats (Figure 1). Subregion 8 includes the Atlantic coast estuaries from Biscayne Bay to Barnes Sound. This area is characterized as shallow water of natural salinities with extensive seagrass habitat which is important nursery areas for reef species. Florida Bay proper is included with the fringing mangrove habitat. This subregion continues up the west coast and included estuaries from Whitewater Bay to Lower Charlotte Harbor and includes extensive mangrove habitat. The Florida Keys include hardwood hammocks, coastal strand communities, and fringing mangrove, beach or rocky habitat. The reef tract is characterized by a rich biodiversity which requires clear, naturally oligotrophic ocean water. This report presents a plan for research for this subregion with the purpose of promoting recovery as defined by the Science Sub Group Report on the Federal Objectives for the Restoration of South Florida. The restoration objectives are largely dependent upon the restoration on freshwater delivery and quality to the subregion. The focus of restored freshwater inflow includes redirecting flow into Biscayne Bay, Card Sound, and Barnes Sound via the C-111 system; and restoring flow into northern Florida bay via Taylor Slough and Shark Slough. A review of existing management and research plans was completed to determine the extent of area within the subregion covered under such an existing plan with emphasis on restoring freshwater inflows into the estuaries of subregion 8. In addition, upland impacts, particularly related to continued development of the Florida Keys was evaluated relative to inclusion in existing plans. The areas included under existing plans were plotted as shown on Figure 2. Gaps in areas or information were identified and highlighted for consideration for the restoration of the subregion as a whole. These gaps resulted in the research recommendations included in this plan. Finally, a complete bibliography is attached with hundreds of individual references relevant to this subregion.

MAJOR ISSUES

The diversity of this subregion is such that while there is much information available on each area there is no information on how these areas are linked either physically or biologically. In particular, the impact of waters adjacent to the subregion including, fresh, estuarine, and oceanic on the hydrography is not well described nor are the impact of these processes on the ecology of the area. Specifically the following questions have been developed which need to be addressed: 1) how hydrological changes, both in the quality and quantity of fresh, estuarine, and oceanic waters from all boundaries will impact the coastal waters and associated habitats from Barnes Sound to Charlotte Harbor; 2) how will sealevel rise impact the area and interact with anthropogenic changes; 3) how does water quality impact subregions upstream from subregion 8; 4) how will altering the hydrology of south Florida be effected by continued development in Monroe, Dade and Collier counties; 5) what are the main land sea human interactions within the area. There are numerous plans that have been developed or are already in place which address the management of specific areas within the subregion. To determine the extent to which these plans address these critical questions, all these plans were reviewed. One plan which is in the process of implementation is included with this report because it includes most of the total area within the subregion. This plan is the Interagency Science Plan for Florida Bay. Notably, there are 41 plant and animal species within the area listed as endangered or threatened under the Endangered Species Act, 1973 (ESA) or under review for listing under the ESA. For the 22 species currently listed, all either have Recovery Plans completed or are in the process of completion. A list of these species is included (Table 1).

REVIEW OF EXISTING RESEARCH AND MANAGEMENT PLANS

Interagency Science Plan for Florida Bay. This research plan was developed for the estuarine and marine waters of Florida Bay and including the Florida Keys and the reef tract. Included are all the federal and state agencies with research and management responsibilities for this area and are: 1) Dept. of Interior (NPS/ENP, NBS, USGS) with responsibilities for Florida Bay proper; 2) Dept. of Commerce (NOAA) with responsibility for the Florida Keys National Marine Sanctuary and marine endangered and protected species including cetaceans and turtles; 3) Florida Dept. of Environmental Protection (FDEP) with statutory responsibility for state waters and living marine resources in state waters; and 4) the South Florida Water Management District with statutory responsibility for upstream hydrology. This document establishes a comprehensive research plan for the Bay and adjacent waters which is based on with the goal of meeting the criteria for ecological restoration. The review of historical information has resulted in the identification of information gaps which in turn results in the identification of research needs. These needs are couched around a series of 14 research questions which were originally presented in the Draft ENP Research Plan for Florida Bay; the Boesch et al. report; a NOAA draft workshop report on Florida Bay; and the internal working documents for the FDEP, SFWMD, and the USGS. This plan defines the area to include Florida Bay and the Florida Keys. Four major research topic areas were considered: 1) water budgets, circulation dynamics, and salinity; 2) water quality and nutrient cycling; 3) seagrass, mangrove, and hardbottom habitats; and 4) living resources and biodiversity. Based on the information reviewed relative to these topics, key research needs were identified under each topic. It was clearly noted that the impacts of changing the flow of water into the Bay on the circulation dynamics; ecosystem dynamics; and living marine resources of the Bay and adjacent waters are not known. As noted by the Science Sub-Group Report, the criteria for success in restoration is met primarily by restoring the ecology of the sub-region and measured by the abundance, diversity, and viability of living resources. This plan addresses questions 1 and 3 relative to Florida Bay proper.

Water Quality Protection Plan for the Florida Keys National Marine Sanctuary. This plan is a joint EPA NOAA effort as mandated to the EPA. The Florida Keys are a limestone island archipelago extending southwest over 320 km from the souther tip of the florida mainland to the Dry Tortugas, and 101 km west of Key West. they are bounded on the north and west by Biscayne Bay, Barnes and Blackwater sounds, Florida Bay, and the Gulf of Mexico. The Sanctuary includes 9500 km^2 of submerged lands and waters between the southern tip of Key Biscayne and the Dry Tortugas Back. North of Key Largo it includes Barnes and Card sounds, and to the east and south the oceanic boundary is the 300 m isobath. The FKNMS includes part of Florida Bay and the entire Florida Reef tract, the largest barrier reef system in the continental shelf. The plan recognizes that degradation and changes in the various habitats has been reported likely the result of the continued development of South Florida. It is also noted that the impact of the hydrological changes in the Everglades on the FKNMS is not known. During the past century, the pattern and intensity of freshwater flows to the estuaries of south Florida have been significantly effected with the construction of the C and S F Project for Flood Control. Historically, freshwater input to the area was via rainfall. This plan requires that a long term strategy be developed to obtain information on the status of water quality and biological resources in the Sanctuary. Both the hydrography and quality of water were changed with the establishment of the C and SF Project to the determinant of the FKNMS. The intention of this strategy is to allow for intervention and mitigation as needed to protect the FKNMS and it's various communities. The plan indicates that a suite of physical parameters will be monitored both in the water column and the sediments. In addition, pollutants and nutrients will be monitored. Biological monitoring is based on a habitat approach using both in situ and remote methods. Changes in communities quality and structure will be assessed. In addition to the EPA and NOAA, the plan recognizes that FDNR is responsible for establishing and maintaining the database that results. The current status of this plan is a draft, however, final approval is imminent(M. McGehee, EPA). While the plan currently identifies activities through FY98 it is noted that the activities are intended to be ongoing beyond this period. The major activities identified include : 1) develop phased hydrodynamic/water quality models and couple with landscape level ecological models to predict and evaluate the outcome of alternative water quality management strategies; 2) develop a segmentation framework to identify surface water areas sharing common hydrographic properties effecting water quality; 3) conduct research to identify and document causal linkages between water quality and ecological problems in each system; 4) develop diagnostic

indicators of water quality problems and conduct research to identify and evaluate indicators in each system; 5) conduct research to identify and evaluate innovative monitoring tools and methodologies to detect pollutants and identify cause/effect relationships involving water quality and biological resources; 6) work with appropriate agencies regarding hydrology of South Florida and impacts on Florida Bay and the FKNMS and conduct research on impact of flow from the Bay on the FKNMS; and 7) examine the effects of global climate change on the organisms and ecosystems of the Keys. All five questions are addressed by this plan relative to the FKNMS.

Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. This plan as developed by the South Florida Water Management District provides for long term funding or develop mechanisms for long term funding; and provide the support (including technical) to initiate or continue specific activities to improve the water quality for this area. The area extends from the Dade/Broward Counties line west to the C-111 canal system and south to Barnes Sound. Historically, the area received freshwater sheet flow from the Everglades. However, over the past several years drainage of the Everglades, construction of the Intracoastal Waterway, and continued development has resulted in reduced circulation, increased turbidity, habitat destruction, and altered salinity patterns. The plan recognizes the multitude of problems and issues related to water quality and the impacts on the diverse habitats and how to ameliorate these to meet the SWIM legislation and FDEP regulations. The two major issues that are addressed are water quality and freshwater inflow and the impacts of these on living resources and habitat. It is noted that the pulsed nature of large freshwater input from canals has had major negative impacts on the Bay and it's structure. The plan in particular notes the importance of upland communities which act as filters for the freshwater inputs into the Bay. Mitigation of upland communities is noted as important to maintain the water quality of the Bay. There are 24 recommendations included which relate to improving and maintaining water quality and quantity into the Bay and the impacts of these on the physical and ecological dynamics and properties of the Bay. All five questions are addressed by this plan for Biscayne Bay.

FKNMS Draft EIS and Management Plan. This plan is the umbrella under which the above is included. The same information relative to the pre and post Everglades drainage is included and the impact of this on the FKNMS. However, in addition to addressing issues/research on hydrology, water quality and hydrography it includes strategies relative to boating, recreation, and land use. One result of this plan was the development of the Marine Reserve strategy now in consideration. This strategy will result in the establishment of areas where non-consumptive use of resources is mandated. This plan largely addresses the needs of maintaining the Sanctuary by minimizing impacts by controlling human activities within the Sanctuary.

The West Florida Shelf: Past, Present, and Future. This document presents the results of a workshop hosted by FIO in 1992 with sponsors including FDEP, EPA,and NOAA. Subregion 8 is subsumed in the entire area of concern in this report which was convened with the purpose of reviewing information to develop an integrated approach to continued research in support of management. The surface circulation of the area is dominated by the Loop Current which exits through the Florida Straits (Keys) to form the Florida Current and then the Gulf Stream. The position of these currents is traditionally determined via temperature and depth. It is noted that the coastal intrusions of the Loop Current has significant impact on coastal waters and are both spatially and temporally unpredictable and result in upwelling. Wind is also known to generate coastal movement and entrapment of current water. These processes are hypothesized to propagate cold, high salinity, nutrient-rich water into the coastal zone and catalyze red tides. The west Florida shelf (WFS) circulation within subregion 8 is characterized by a coastal regime influenced by the estuaries upstream and within the area including Tampa Bay and Charlotte Harbor in addition to the tidal and wind forced processes. This document describes the southern area of the WFS as a distinct sub region coupled to the northern areas. The southern area is within sub region 8 and if from Florida Bay to the Keys and is described as an area of carbonate sediments, coastal mangroves, seagrasses, and coral reefs. Research in this area focuses on the physical characteristics of the area including hydrography and geology and the resulting ecology. Physical, geological, chemical, and biological studies have extended from the Florida Keys through Florida Bay providing information for the southern system. Upstream influences from freshwater inputs are unknown particularly as related to the alternative hydrology of the Everglades. Waters within subregion 8 are transported via the Gulf Stream along the Atlantic coast, and the impact of these waters (quality) is not known.

Surface Water Improvement and Management Plan for the Everglades. As for Biscayne Bay, this plan describes activities relative to improving water quality in the Everglades including Florida Bay. The Bay area is described as from Barnes Sound to Long Key Basin and up through Whitewater Bay and adjacent coastal swamps and lagoons. The impact of the C&SF Project has resulted in water quality changes which have impacted the diverse habitats within the Bay. In particular, water quality problems appear to be in the Central Bay; Barnes Sound and Manatee Bay; and the basins and sounds along the shoreline of the Florida Keys. These problems are due in part to the hypersaline conditions which now exist. The shoreline of the Keys is identified as an area of particular concern which requires additional protection. The major information needs are included and those which remain have been incorporated into the Interagency Science Plan for Florida Bay described above.

An Environmental Characterization of the Rookery Bay National Estuarine Research Reserve: Phase I. This document reviews over 130 documents on Rookery Bay. It is noted that this estuary which is located in Collier County is part of the National Estuarine research Reserve System and managed jointly by NOAA and Fl DEP. The estuary extends from Marco Island to Naples and is characterized by upland habitats, mangrove forests (the dominant habitat type), freshwater ponds, both fresh and salt marshes, mudflats, oyster bars, seagrass beds. Research directed at the physical, chemical, and biological characteristics and processes began in the early 1970's. The largest and most extensive data base relates to water quality studies which have been conducted annually since 1970. Monitoring has focused on birds, and pesticides in mangrove forests leading to mangrove restoration efforts. Within the estuarine waters, monitoring has focused on manatees and fisheries resources. It is anticipated that water quality will change as a result of human impacts upstream from the estuary. These human impacts include development to accommodate 125 immigrants per week and agriculture. Naples is described as the fastest growing area in the U.S in the 1980's and the impact of continued growth is not known. Determining and predicting the spatial and temporal patterns of freshwater inflow is critical to reserve management.

NOAA's Florida Bay Implementation Plan. This is the first such plan which identifies research underway and proposed specifically to address research needs for Florida Bay. The plan defines what NOAA is currently doing and what will be initiated this fiscal year. This plan is designed to address those research needs in the Interagency Science Plan for Florida Bay by applying NOAA's expertise to answer specific research questions. With the implementation plans for each agency, the sum then should reflect the research needs identified in the Interagency Science Plan for Florida Bay.

Management Agreement for Backcountry Portions of Key West National Wildlife Refuge; Great White Heron National Wildlife Refuge; and National Key Deer Refuge. This plan is between the Fish and Wildlife Service and the state of Florida and provides the framework for the establishment and use of the National Wildlife Refuges of the Florida Keys and Florida Bay. While this plan outlines the uses and regulations for these wildlife refuges it does not address research or does not represent a comprehensive strategic plan for the refuges as a whole.

RECOMMENDATIONS

1. The FWS needs to develop a comprehensive strategic plan that includes all the wildlife refuges as a whole within the subregion and perhaps within the state. A research implementation plan must also be developed which needs to include impacts of continued development on habitat especially as related to endangered species. Research priorities include: a) determining the ecology and status of the Key deer and impacts of habitat loss or change on population status and condition; b) impact of prescribed burning on habitat, especially needed is a determination of when and how frequently burning needs to be completed if at all; c) an inventory of species with emphasis on endangered species and determination of candidate species for listing under the ESA.

2. The only coastal areas not included under an existing plan, are a) a small area of the bay adjacent to both the Florida Keys National Marine Sanctuary and the Everglades National Park and b) the northern and

southeastern parts of Biscayne Bay. To offer full protection this area needs to be included within under an existing plan. Both DOI/NPS (including the Everglades National Park and Biscayne National Park), the DOC/NOAA and the state of Florida/DEP need to determine how to best include these waters in their areas to insure proper management and protection.

3. Each agency needs to develop an implementation plan relative to their jurisdictional responsibilities. Plans need to be complementary and supplementary in scope and all attempts to minimize overlap must be made.

4. A complete biological inventory of the sub-region must be completed by the agency with primary jurisdictional responsibility for each area within the subregion. Monitoring of all endangered and threatened species must be continued to insure recovery.

5. Linkages between upland influences relative to coastal habitat need to be better defined and identified in all existing plans.

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TABLE 1

END = Endangered; THR = Threatened; UR = Under Review; THR/SA = Listed Threatened due to Similarity of Appearance; SSC = Species of Special Concern

	STATUS	
ANIMAL SPECIES	FEDERAL	STATE
Am. Alligator	THR/SA	SSC
American Crocodile	END	
Loggerhead Turtle	THR	
Atl. Hawksbill Turtle	END	
Atl. Green Turtle	END	
Atl. Ridley Turtle	END	
Leatherback	END	
Indigo Snake	THR	
Rim Rock Crown Snake	UR	THR
Piping Plover	THR	
SE Snowy Plover	UR	THR
White Crowned Pigeon	UR	THR
Peregrine Falcon	THR	END
Bald Eagle	END	THR
Wood Stork	END	
Roseate Tern	THR	
Key Largo Cotton Mouse	END	
Key Largo Woodrat	END	
Silver Rice Rat	END	
Lower Keys Marsh Rabbit	END	
Key Deer	END	
Manatee	END	
Schaus Swallowtail Butterfly	END	
PLANT SPECIES		
Blodgett's Wild Mercury	UR	END
Big Pine Partridge Pea	UR	THR
Prickly Apple Cactus	UR	END
FL Tree Cactus	END	
Wild Thyme Spurge	UR	END
Keys Hairy Podded Spurge	UR	END
Porter's Broom Spurge	UR	END
Garber's Spurge	THR	END
Two-Spike Finger Grass	UR	
Dollar Orchid	UR	END
Pineland Privet	UR	
Pineland Clustervine	UR	END
Sand Flax	UR	END
Small Leaved Cat's Tongue	UR	
Florida Five-Petaled Leaf Flower	UR	
Bloykin's Few-Leaved Milkwort	UR	
Noseburn	UR	END
Florida Gama Grass	UR	

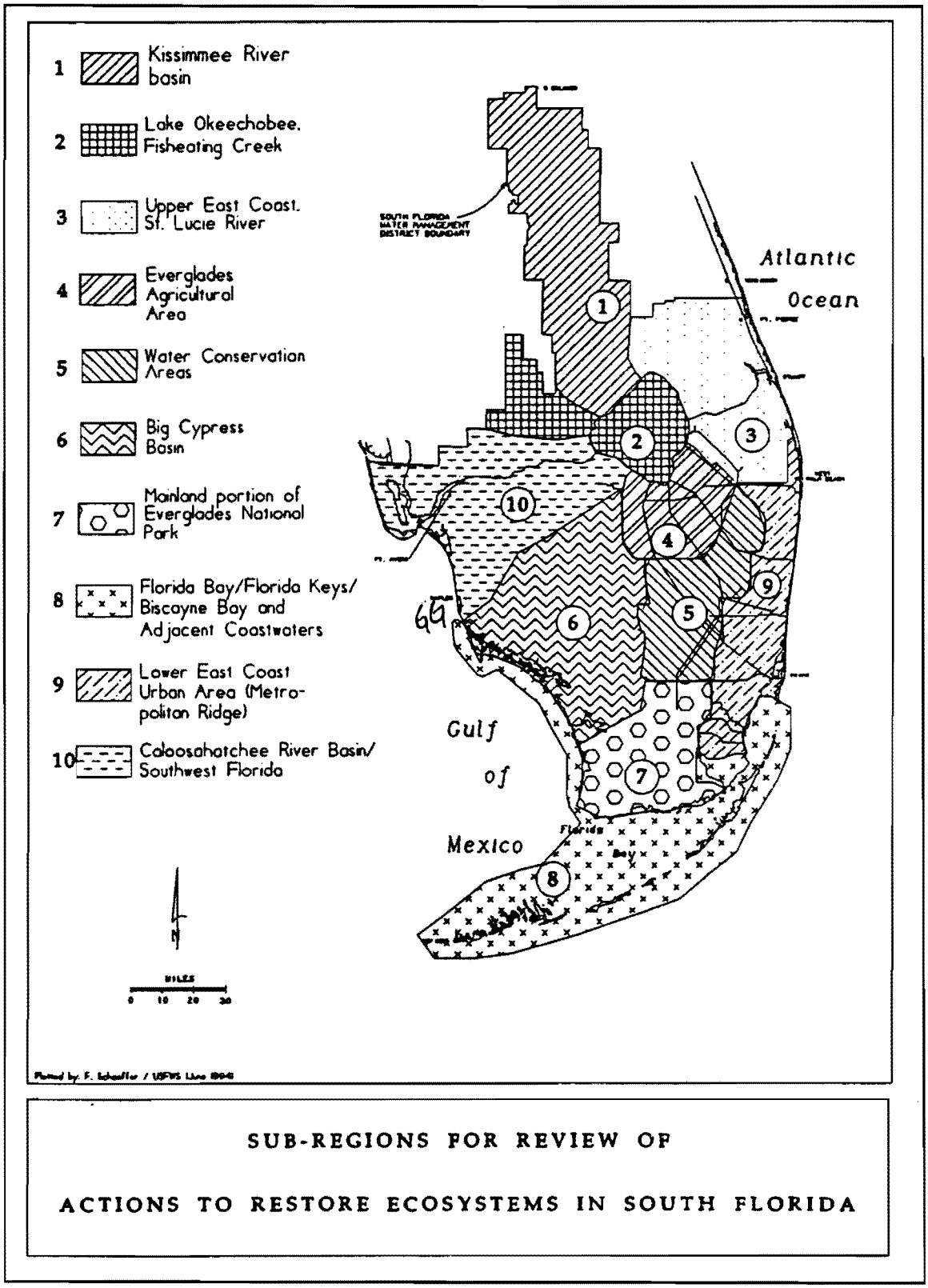

1 Kissimmee River basin
2 Lake Okeechobee, Fisheating Creek
3 Upper East Coast, St. Lucie River
4 Everglades Agricultural Area
5 Water Conservation Areas
6 Big Cypress Basin
7 Mainland portion of Everglades National Park
8 Florida Bay/Florida Keys/ Biscayne Bay and Adjacent Coastwaters
9 Lower East Coast Urban Area (Metropolitan Ridge)
10 Caloosahatchee River Basin/ Southwest Florida
SOUTH FLORIDA WATER MANAGEMENT DISTRICT BOUNDARY
Atlantic Ocean
Gulf of Mexico
Florida Bay
MILES
0 10 20 30
SUB-REGIONS FOR REVIEW OF
ACTIONS TO RESTORE ECOSYSTEMS IN SOUTH FLORIDA

Figure 1.

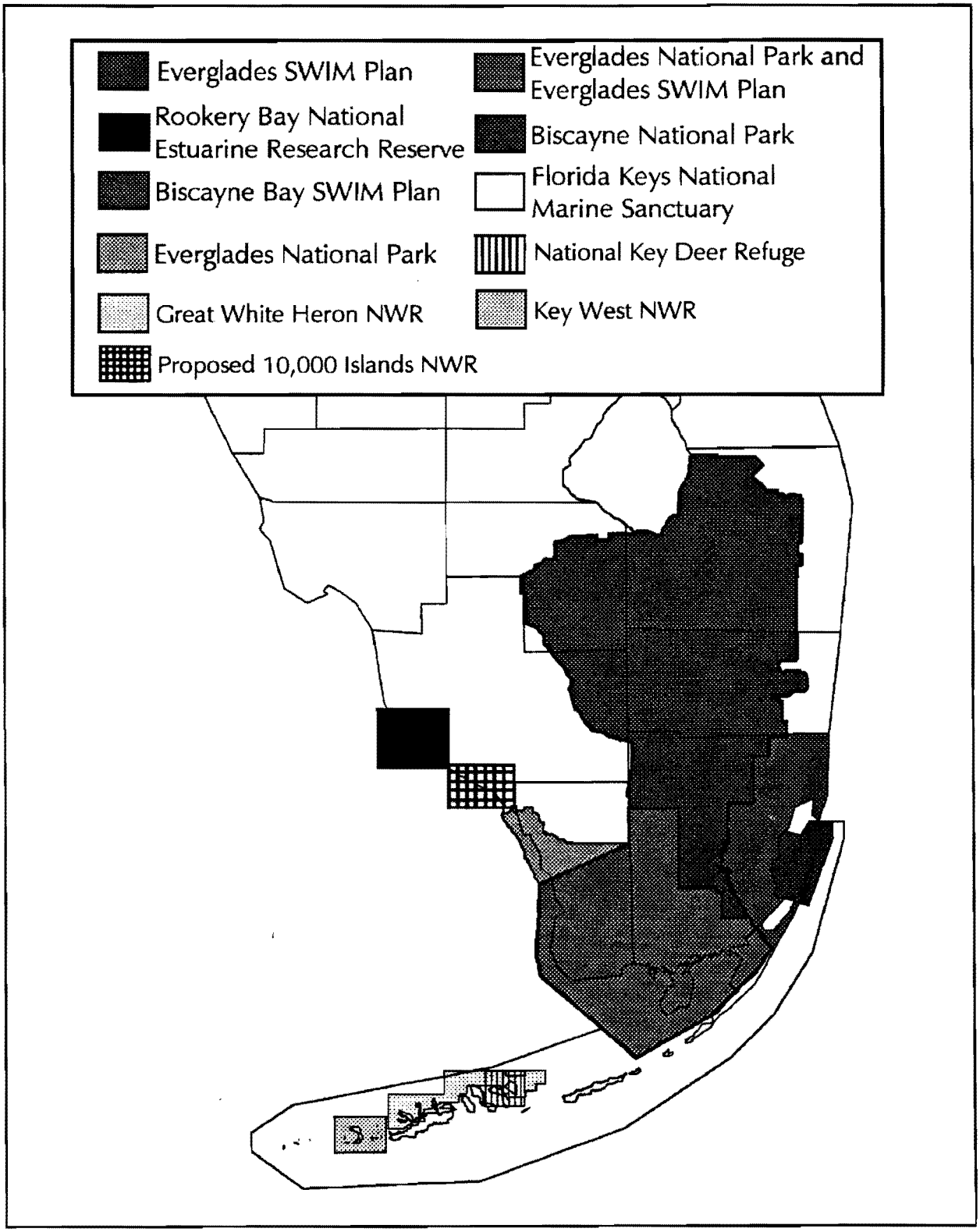

Everglades SWIM Plan
Everglades National Park and Everglades SWIM Plan
Rookery Bay National Estuarine Research Reserve
Biscayne National Park
Biscayne Bay SWIM Plan
Florida Keys National Marine Sanctuary
Everglades National Park
National Key Deer Refuge
Great White Heron NWR
Key West NWR
Proposed 10,000 Islands NWR

Figure 2.

FLORIDA BAY SCIENCE PLAN

A science planning document provided to the Interagency Working Group on Florida Bay

April 1994

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I. EXECUTIVE SUMMARY

The following science plan was developed by the Florida Bay Interagency Working Group, which was initiated by Everglades National Park in January 1993. The plan focuses upon the research, monitoring, and modeling objectives that must be addressed to guide the restoration of Florida Bay and represents a synthesis of research plans prepared over the past year by several federal and state agencies. With additional plans focused on the coastal mangrove estuaries of southwest Florida, the Florida Reef Tract, and, the Florida Keys and Dry Tortugas, this science plan will serve as the basis for restoration of Sub-region 8 under the aegis of the South Florida Ecosystem Task Force.

Administratively, an interagency research plan for Florida Bay is especially needed because of the number of agencies that have jurisdiction over areas affected by Florida Bay research and restoration. Representatives of the major agencies (Department of Commerce, Department of Interior, Florida Department of Environmental Protection, and the South Florida Water Management District) have participated in drafting an interagency plan consistent with their respective responsibilities. As recommended by a disinterested advisory panel convened in September 1993 at the behest of the Assistant Secretary of the Interior for Fish and Wildlife and Parks, a management framework has been explicitly set forth to ensure continuing integration of the activities of the different agencies. This framework includes an Interagency Program Management Committee, a Review Panel, and a Technical Advisory Group. It was agreed that individual implementation plans prepared by each agency should not only be consistent with the scientific approach and priorities of the interagency science plan but each should also include the following:

1) Cross-references to and discussions of the implementation plans developed by other agencies,

2) A funding source for participation in annual interagency principal investigator meetings at which data and results can be exchanged, and

3) Compatible data-management plans and procedures.

The management objective for Florida Bay is to restore it to a naturally functioning ecosystem. Elements of the restoration process and the degree to which management can effect change, in large part, define the focus, approach, and priorities of this science plan. To support restoration, the science program must be long-term and goal-oriented in perspective. The program must be committed to the process of integrating scientific understanding of Florida Bay into the management decision-making process and must focus on interdisciplinary ecosystem-based research. The specific objectives of the science program should include the following:

1) Developing an understanding of the condition of Florida Bay prior to significant alteration by man;

2) Separating anthropogenically induced changes in Florida Bay from natural system variation;

3) Developing a basic understanding of the ecology of Florida Bay by evaluating alternative hypotheses;

4) Developing the capability to predict how the ecosystem as a whole and how a suite of species that collectively may be considered indicators of Florida Bay ecosystem health respond to perturbation.

The approach recommended embraces a closely linked program of monitoring, research, and modeling. By monitoring, we can track critical ecosystem parameters and provide baseline data and model parameterization. By conducting research, we can develop an understanding of the physical and biological processes regulating Bay ecosystem status, test model predictions, and evaluate cause and effect relationships. Computer simulation models, in which our best understanding of the Bay's ecology within the regional landscape is expressed, will be used in a predictive mode to assess system response to change, to hindcast historical conditions, and to develop and select management alternatives.

Four general topic areas were considered: 1) water budgets, circulation dynamics, and salinity; 2) water quality and nutrient cycling; 3) seagrass, mangrove, and hardbottom habitats; and 4) living resources. Following the recommendation of the advisory panel, priorities were then established within each of the general topic areas by formulating questions that must be answered in order to understand the ecosystem of Florida Bay, the changes it has undergone, and the possible effects of alternative restoration scenarios. These are some of the questions posed:

1. What is the relationship of surface water and groundwater flows through the Everglades to the salinity of Florida Bay?

2. What has been the effect of the relative lack of storms over the past three decades on the buildup of sediments, nutrients, and organic material in the Bay?

3. What have been the effects in Florida Bay of increased residence time of water caused by restricted water flow through channels between the Keys, shoaling, and reduced freshwater inflows?

4. What are the sources, quantities, and ecological effects of "external" nutrients introduced into Florida Bay?

5. What are the rates of nutrient exchange between the sediment and water column within Florida Bay, and what controls the magnitude and direction of these fluxes?

6. What are the rates of nutrient assimilation by phytoplankton in the Bay, and what limits the growth of the phytoplankton assemblage?

7. What are the sources, quantities, and effects of toxic pollutants introduced into the Florida Bay ecosystem?

8. What is the cause of turbidity in the Bay, and what is its effect on Bay water quality?

9. What environmental and biological factors explain the observed distribution of seagrasses within the Bay and the recent die-off?

10. What environmental factors explain the pattern of mangrove die-back within the Florida Bay ecosystem?

11. What has been the cause and consequence of sponge die-off and the subsequent alteration of hardbottom communities?

12. Has recruitment into Florida Bay been affected by habitat changes in Florida Bay, and have altered environmental conditions affected growth and survival of animals in Florida Bay?

13. Has habitat degradation or loss caused a reduction in fishery productivity in the Bay?

14. Have environmental and habitat changes in the Bay affected the distribution and reproductive success of higher-trophic-level consumers?

II. INTRODUCTION AND FRAMEWORK

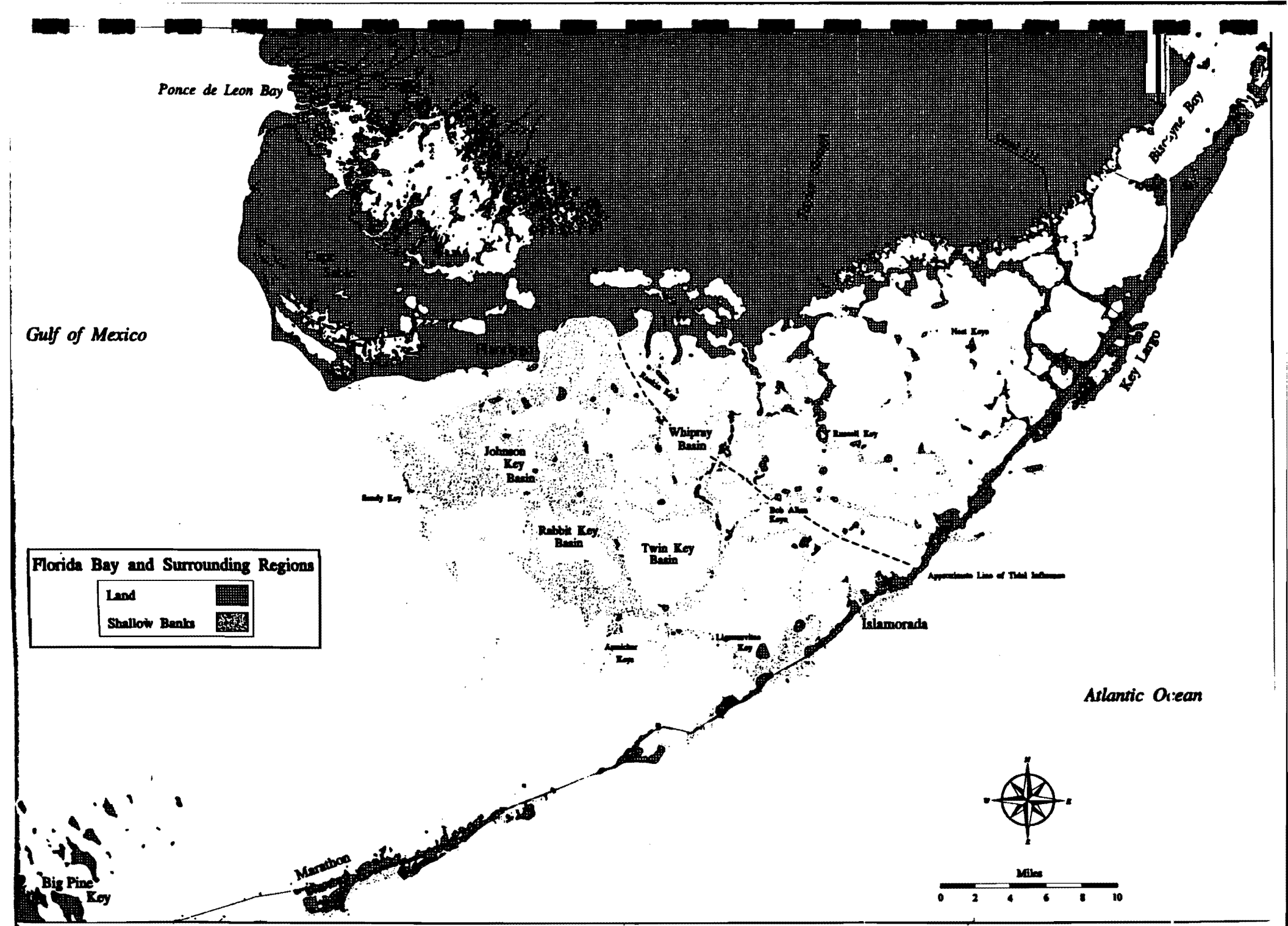
A. Context

Since 1987, a series of changes in Florida Bay (Fig.1) have become evident to even the most casual observer. To date, these have included extensive losses of seagrass habitat, diminished water clarity, micro-algal blooms of increasing intensity and duration, and population reductions in economically significant species such as pink shrimp, sponges, lobster, and recreational gamefish. In response to heightened local concern, the representatives of a number of state and federal agencies began meeting in January 1993 as an informal Working Group for Florida Bay. In fact, however, not only Florida Bay but the entire South Florida ecosystem, a unique, interdependent landscape-seascape, may be threatened. With national attention to this crisis, the relevant federal agencies (see below) entered into an historic Agreement[1] to cooperate and work with the State of Florida "to address and solve the myriad issues involved in restoring and maintaining the unique world resources embodied in the South Florida ecosystem."

The Agreement established an interagency Task Force consisting of Departmental Assistant Secretaries (or their equivalents) from the Dept. of the Interior (DOI), the Dept. of Commerce (DOC), Dept. of the Army (Civil Works), Dept. of Justice, Dept. of Agriculture, and the Environmental Protection Agency. It is intended that, as soon as possible, the appropriate State of Florida (Department of Environmental Protection/DEP) and regional (South Florida Water Management District/SFWMD) agencies will be invited to become members of the Task Force and its subsidiary bodies. The Task Force has already established a South Florida Management and Coordination Working Group consisting of local administrators, which has in turn established, among other advisory subgroups, a Scientific Working Sub-Group to provide necessary technical advice. This last body began to meet in October 1993, and, at the request of the Army Corps, has provided the South Florida Management and Coordination Working Group (and Task Force) with a set of objectives and success criteria for the hydrological and ecological restoration of the South Florida Ecosystem. Objectives and criteria were separately provided for ten subregions, which were viewed not as a set of isolated geographic areas but rather as an integrated whole[2].

For each subregion (or combinations thereof), detailed science plan have been developed that will be integrated into a regional, ecosystem-based science program. The Agreement not only envisions such integration, but also explicitly sanctions line agency cooperation and facilitates mechanisms (e.g., interagency transfers of funds) needed to accomplish efficient integration.

The document to follow was developed at the request of the chairman of the South Florida Management and Coordination Working Group for Florida Bay, the Superintendent of Everglades Park. It represents the first interagency science plan for any South Florida subregion since the Agreement was executed.


Ponce de Leon Bay
Gulf of Mexico
Biscayne Bay
Key Largo
Whipray Basin
Johnson Key Basin
Rabbit Key Basin
Twin Key Basin
Bob Allen Keys
Islamorada
Atlantic Ocean
Marathon
Big Pine Key
Florida Bay and Surrounding Regions
Land
Shallow Banks
Miles
0 2 4 6 8 10

The following plan focuses upon the research, monitoring, and modeling objectives that must be addressed in the restoration of Florida Bay. The substance of this plan is a synthesis of the following: a draft research program for Florida Bay developed by the National Park Service's South Florida Research Center (now the South Florida Natural Resources Center)[3]; a draft report from a NOAA workshop held to define Florida Bay research priorities[4]; and the internal draft research plans recently prepared by the South Florida Water Management District, the Florida Department of Environmental Protection, and the United States Geological Survey. The synthesis effort was preceded by a scientific review of Florida Bay problems conducted by a panel of nationally recognized scientists, as requested by Assistant Secretary Frampton (DOI)[5].

B. Management Responsibilities and Research Activities

Administratively, an interagency research plan for Florida Bay is essential because of the number of agencies that have jurisdiction in Florida Bay or in ecologically connected areas. The principal federal "research" agencies are in the DOI and the DOC. Approximately 85% of Florida Bay lies within the Everglades National Park, and the National Park Service (DOI) also manages the adjacent Dry Tortugas and Biscayne National Parks. Under the Organic Act of 1916, the NPS is responsible for both protecting and preserving these unique environments. For the past several decades, the ENP has both conducted its own research in Florida Bay and funded academic researchers. Moreover, the Fish and Wildlife Service (DOI) has twelve national wildlife refuges in the South Florida regional ecosystem as well as significant responsibility under the Endangered Species Act (ESA) for endangered terrestrial species utilizing the Bay and adjacent coastal wetlands.

The remainder of the Bay lies with the Florida Keys National Marine Sanctuary, which is managed by the National Oceanic and Atmospheric Administration (NOAA/DOC) under the National Marine Sanctuaries Act. Sanctuary managers now have an explicit mandate to look upstream outside its boundaries, if necessary, to protect the FKNMS's unique coral habitats. In 1990, Congress directed EPA and the State of Florida, in conjunction with NOAA, to develop a comprehensive water-quality protection program for the Sanctuary.

The Bay is a critical nursery habitat for recreationally and commercially fished species and is the habitat of protected marine mammals and a number of threatened and endangered marine species. The National Marine Fisheries Service (NMFS/NOAA/DOC) is responsible for research on and conservation of living marine resources and their habitats under the Magnuson Fishery Conservation and Management Act of 1976, for marine mammals under the Marine Mammal Protection Act, and for endangered marine species under the Endangered Species Act. Moreover, under the Fish and Wildlife Coordination Act, NMFS is charged with representing the interests of living marine resources in government decisions regarding land and resource management or development. NOAA/NMFS has been conducting research in the Bay since the early 1980's.

The USGS, which has no management responsibilities for Florida Bay, maintains long-

term ground-water and surface-water monitoring programs in South Florida that are expanding this year through the USGS's National Water Quality Assessment (NAWQA) Program. This monitoring provides baseline data on water flow into the coastal areas. Coastal processes including erosion, deposition, and sediment transport and certain associated pollutants are evaluated by the Marine and Coastal Program of the USGS.

The principal state management agency is the Florida DEP. The state manages fisheries within its territorial waters and since 1983 has been conducting research aimed at assessing the pre-fishery recruitment of resource species which utilize estuarine and near-coastal areas. The Florida Marine Research Institute (DEP) has recently implemented a substantial monitoring program in Florida Bay and has proposed that it be significantly expanded in the next legislative session.

Last, and perhaps most critically, neither the National Park Service (DOI), NOAA (DOC), nor DEP controls the fresh water delivered to Everglades National Park and in turn to the Bay. Water delivery is regulated by the South Florida Water Management District (SFWMD) in conjunction with the Army Corps of Engineers (DOD). The SFWMD conducts its own research in the Bay and sponsors academic research through the ENP.

No one agency has sufficient management control, scientific expertise, and financial resources to independently solve the problems of Florida Bay. As concluded by Boesch *et al.*, "surely, the problems of Florida Bay are so severe and the difficulties in understanding them so challenging that Interior, NOAA, EPA, the Corps, Florida DEP, the South Florida Water Management District and Florida universities can find a way to make complementary contributions and encourage synergy in the scientific enterprise."[5] It is our hope that this plan is a major step in that direction.

C. Management Framework for Florida Bay Research

1. Interagency Florida Bay Program Management

To assure that the broad range of scientific activities planned for Florida Bay are integrated, an interagency Program Management Committee (PMC) will be established consisting of representatives from each federal agency, the Florida DEP, and the SFWMD. Each participating agency will be responsible for drafting its own detailed Florida Bay Implementation Plan. The primary role of the interagency PMC will be to review each of these implementation plans as they are completed to assure that they are consistent with this Interagency Florida Bay Science Plan. The PMC also will attempt to take advantage of the particular scientific and institutional strengths of the participating agencies. Thus the PMC will assure that each of the critical science priorities defined by the cooperating agencies is addressed by the agency or agencies best suited to do so. The science priorities will be based on research needs, which will form the basis for the scientific requirements of restoration and support any restoration plan developed by responsible agencies.

The NPS, through Everglades National Park, accepts responsibility for leading deliberations on Florida Bay restoration planning, for setting scientific priorities, and for coordinating the science programs conducted in Florida Bay. The Park's responsibility includes convening management groups and regularly communicating relevant information to agencies and institutions. The Park will use its permitting process to track the initiation of new projects and to track the reporting of results from these projects as required by the permits.

Given differences in practice and institutional experience, implementation plans may differ markedly-- e.g., some agencies award contracts, whereas others issue grants; some use panel review, and others use mail review; some conduct their own research, others primarily fund academic scientists, and still others rely upon formal government-academic cooperative units. This plan endorses no particular approach. However, the overall program must be as integrated as possible so that each implementation plan is complementary. Explicit cross-references and discussions of implementation plans developed by the various participant agencies will, therefore, be required in all agency implementation plans. A second important role of the PMC will be to provide additional discussion about and review of decisions made within individual research agencies. It is assumed that PMC agency representatives will communicate recommendations made at PMC meetings to their administrative superiors. It is further assumed that, if recommended by the PMC, administrators authorized to develop Florida Bay science plans and programs for their agencies will modify current plans and introduce new elements into future plans.

Experience in multi-institutional interdisciplinary scientific programs shows that improving communication between the principal investigators is instrumental to the program's success. This is even more critical when the scientists work for different agencies and those agencies have different funding mechanisms. All agency implementation plans will at least have to provide for their scientists' participation in annual meetings of principal investigators. Funding for requisite electronic interconnection, InterNet, and/or OMNET is also highly desirable. All agency implementation plans should also provide for their scientists' participation in annual agency (or multi-agency) program reviews.

Agencies will be expected to specifically address data management in their implementation plans. Too often this is added as an afterthought, but given the multi-institutional, interdisciplinary nature of the science proposed herein, efficient integration of all the information generated is critical to the program's success. The data policy for the overall federal interagency program should be consistent with that already agreed upon for the interagency U.S. Global Change Research Program.[6] In brief, this requires early and continuing commitment to maintaining and distributing data, full and open sharing of data, archiving of data, assuring data accessibility, limiting periods of exclusive principal investigator access to an as-needed basis only, and using nationally and internationally approved standards wherever appropriate. Individual implementation plans should include a data management function and centralized databases that can be readily linked to and integrated with those implemented by other agencies.

To assure scientific quality, an interagency Technical Advisory Group (TAG) consisting of scientists representing a broad range of disciplines will be appointed to advise the PMC on the complex technical issues certain to arise in setting research priorities and planning programs. Membership will consist predominantly of principal investigators funded by the different agencies but will not be restricted to that group. Members could be added to the TAG as needed to address particular short-term needs and the TAG could also establish semi-permanent subgroups to address recurrent issues such as interdisciplinary modeling, reviewing proposals for new work and evaluating scientific priorities.

2. Florida Bay Scientific Review Panel

An interdisciplinary panel of nationally recognized scientists will be invited to become members of an interagency Florida Bay Scientific Review Panel. Its role will be to provide periodic, broad, technical review of agency plans, PMC recommendations, and research results. The group will be asked to attend annual agency (or interagency) program reviews and to provide written comments and specific suggestions as to how programs can be improved. The panel will assist the agencies in setting science priorities for the Bay. Membership would be for at least four years and terms would be staggered. Membership continuity is essential to assure institutional memory--i.e., to ascertain whether programs have been responsive to the panel's review and what suggestions have proven helpful. Members of the panel will have to forego subsequent research as investigators funded under the interagency Florida Bay Science Plan.

3. General Policy Oversight

Assuming that state and regional agencies are officially incorporated into the South Florida Task Force, and the South Florida Management and Coordination Working Group, policy oversight will be provided by the Task Force through the Working Group. The Task Force has been specifically charged with coordinating the development of consistent policies, strategies, and plans and with monitoring all restoration-related research programs and activities to assure that they further the overall objective of ecosystem restoration. The Task Force was also established to facilitate the implementation of projects and programs included in the overall interagency coordinated plan for the restoration of the South Florida ecosystem.

4. The Role of the Florida Bay Working Group

As mentioned above, this document is intended to provide guidance and facilitate integration of the research to be conducted by the agencies represented in the Florida Bay Working Group and their cooperators. The PMC will communicate with the Florida Bay Working Group by reporting at Working Group meetings on the progress being made in science program implementation. The Working Group, in turn, can provide the PMC essential feedback from its primary constituents: restoration managers, environmental and economic interest groups, and the general public.

III. GENERAL BACKGROUND

Florida Bay is a triangularly shaped body of water about 2200 km^2 in area. Over 80% of the Bay lies within Everglades National Park. The Bay is bounded by the Florida mainland on the north, U. S. Highway 1 on the northeast, the Florida Keys on the southeast, and the Intracoastal Waterway between Long Key and East Cape Sable. The region west of the Park's western boundary across to the Middle Keys is also commonly considered to be part of Florida Bay. The Bay is shallow, often hypersaline and until recently, was characterized by clear waters and lush seagrass meadows covering a mosaic of shallow-water banks and relatively deeper water basins or "lakes." Deep-water channels (1 to 5 m deep) connect neighboring basins. Hardbottom habitats in southwestern Florida Bay support sponge and hard and soft coral communities. Florida Bay is known as the principal inshore nursery for the offshore Tortugas pink shrimp, Penaeus duorarum, fishery and for providing critical habitat for juvenile spiny lobster, Panulirus argus, and stone crab, Menippe mercenaria. The Bay is the site of an extensive sport fishery and supports populations of the American crocodile, bald eagle, osprey, numerous wading bird species, the bottlenosed porpoise, manatee, several species of sea turtle, and other noteworthy species. Over 200 small islands or "keys" occur in the Bay, all of which are rimmed with mangroves. Most islands have interior, irregularly flooded "flats" with calcareous blue-green algal mats that serve as foraging and resting sites for migratory birds.

Florida Bay exchanges waters with the Straits of Florida through numerous channels between islands and with the Gulf through tidal flux and long-shore currents. In addition, some seepage must occur through the porous Key Largo Limestone. Surface fresh water flows into Florida Bay mainly from Taylor Slough and numerous small streams to the east. Groundwater seepage from the peninsula is believed to be a major but poorly quantified freshwater input. Large flows of fresh water from the Shark River Slough reach Florida Bay only after mixing with Gulf of Mexico water and flowing eastward around Cape Sable. For most of the western half of the Bay, currents are presumed to move in a southerly direction, although few direct measurements support this pattern. Currents on the Bay side of the Upper and Middle Keys presumably flow to the southwest, resulting in a net flow from the Bay toward the Atlantic side through the channels between the Keys. Thus, constriction of the channels between the Keys could reduce net flow of water through the Bay.

The complex bottom topography of the Bay divides it into various subenvironments that have different physical and chemical conditions. The uppermost part of the Bay consists of a number of semi-enclosed sounds that are partly isolated from one another. Southwest of Blackwater and Little Blackwater sounds (northeastern Florida Bay proper), the mud shoals and islands become less numerous, and the area is shallow. Toward the Gulf of Mexico on the mainland side, mud banks increase in width and depth. On the Keys side (toward the Atlantic), the mud banks are narrower and encircle deep, hardbottom "lake" areas.

Northeastern Florida Bay is strongly influenced by seasonal freshwater runoff. Salinities range widely, from brackish to salinities greater than seawater. The interior of Florida Bay is characterized by extremely restricted circulation and widely fluctuating salinities and

temperatures; evaporation exceeds freshwater inflow and direct rainfall. Flushing is slow except for occasional wind-driven transport across shallow boundary sills. In contrast, along the western margin of the Bay, temperatures are relatively moderate and salinities fluctuate near oceanic levels.

The rainy season, May through October, coincides with a seasonal rise in sea level. As the sea level falls (about 15 cm), water of lower salinity reaches well out into the Bay. In addition to this seasonal salinity variation, drought/flood cycles also affect annual salinity ranges. The effects of such cycles can be pronounced. For example, August salinities in northeastern Florida Bay may range from 15 ppt to 50 ppt in successive years, depending on rainfall/runoff conditions. Salinities approaching 70 ppt are reported to have occurred in the central Bay during the droughts of the early 1950s when freshwater supply to the northern Bay was reduced to meet agricultural and municipal requirements.

The Bay is underlain by a floor of extremely flat and permeable Pleistocene limestone that was formed between 125,000 and 145,000 years ago during the last interglacial. This floor gently slopes to the southwest, so that during the last glacial melting, the Bay was flooded from southwest to northeast as sea level approached its present position. During the past 4500 years, peat and carbonate mud have accumulated to form a series of Holocene intertidal mud banks and mangrove islands that now dissect the Bay into shallow basins locally termed "lakes." The present configuration of mud banks is the result of complex deposition and erosion processes that form coastal levees, ponds, storm ridges, migrating islands, and mud banks at various locations throughout the Bay. These sediments are formed from organisms living in the Bay at rates that have easily kept up with sea-level rise during the past few thousand years. Rapid sedimentation may be further restricting the Bay; however, large volumes of sediment are also exported from the Bay, and it is unclear if sedimentation is keeping up with the relatively rapid sea-level rise that has occurred during the last century.

Over the past decade, a number of biological, chemical, and physical changes in Florida Bay have been observed by scientists, tourists, and fisherman who frequent the Bay. Seagrasses in western Florida Bay, principally turtlegrass (Thalassia testudinum) have been dying since the summer of 1987 and continue to as of March 1994. Mass mortality of this magnitude has not been observed previously in Florida Bay nor has it been reported in the scientific literature on tropical seagrasses. Initially, three causes of seagrass die-off were proposed.[5] First, the synergistic effects of several long- and short-term factors appear to have caused a production/respiration imbalance. Second, the observed contagious distribution of die-off patches and the rapidity of the die-off process suggest that a pathogen was the proximate cause of seagrass die-off. Third, eutrophication was considered a possible cause of die-off, although evidence of eutrophication was observed prior to seagrass die-off in Florida Bay.

Several adverse trends have accompanied the die-off, most notably declining water quality as algal blooms have increased in intensity and duration. Declines in the pink shrimp and sport fisheries and the die-back of sponges threatening the lobster fishery have also coincided with seagrass die-off in the Bay.

Conditions that have been present in the Bay since 1988 appear to be associated with, and may result in some way from, seagrass die-off. For example, Florida Bay has had plankton blooms since the seagrass die-off in 1987, but not before. The blooms have reoccurred each year and have become steadily bigger and more persistent as the seagrass die-off has spread to relatively higher-energy areas of the Bay such as Sandy Key Basin. The exposed sediments are resuspended daily by the tides and frequently by winds, increasing turbidity and probably releasing nutrients into the water column.

The most compelling hypothesis for the cause of seagrass die-off involves long- and short-term processes, both involving alteration of freshwater supply to the Bay. Over the long-term period of a half century or more, the diversion of fresh water by upland water management has contributed to increasingly marine-like conditions in Florida Bay. Knowledge of the comparative biology of the seagrasses suggests that this trend has favored the dominance and growth of turtlegrass over other species.

Over the past three decades, Florida Bay has experienced fewer hurricanes compared to the long-term record in South Florida, and water management has diverted peak storm flows that otherwise would have reached Florida Bay. Both trends have had the effect of reducing disturbance of the Bay benthos and sediments. The absence of these high-volume inflows has led to stabilization and deepening of bottom sediments and heavy accumulation of seagrass detritus.

On the time scale of several years, high salinities and elevated water temperatures have been measured in Florida Bay at levels that are understood to cause physiological stress in seagrasses. Both stresses may have contributed to seagrass die-off. In addition, since August 1992, Florida Bay has experienced Hurricane Andrew, the "storm of the century" (in March 1993), and the wettest January (1993) on record. Each of these events, as well as the severe 1989 freeze, may have contributed to the present status of Florida Bay.

IV. ORGANIZING STRATEGY

A. Restoration Perspective

The management objective for Florida Bay is to restore it to a naturally functioning ecosystem. The restoration process and the degree to which management can effect change define, in large part, the focus and priorities of the scientific activities supporting Florida Bay restoration.

Restoration as a goal assumes, *a priori*, that the Bay has been impacted by man. The current perception of Florida Bay is that the Bay is a system in decline. Seagrass die-off, persistent plankton blooms, extensive turbidity, and declining commercial and recreational fisheries are thought to be the consequence of accelerating human population growth, land use changes, the expansion of agriculture, and the development of increasingly invasive and environmentally destructive water-management practices in the headwaters of Florida Bay. Although it is probable that the Bay is, and has been, strongly impacted by man's activities in

South Florida, cause and-effect relationships have not been rigorously determined. Long-term natural changes have not been clearly separated from those that result from human intervention. Various hypotheses have been put forth to explain current problems in the Bay. These are not mutually exclusive. However, limitations of the means available to direct change in Florida Bay strongly argue for a research program that emphasizes hypotheses linked to manipulation of the quality, quantity, timing and distribution of freshwater inflow to the Bay.

Defining a realistic restoration endpoint is an important step. To what condition, to what status, do we seek to return the Bay? In one sense, restoration implies that the natural ecological condition for the Bay is known or can be known. Since 1988, Florida Bay has definitely differed from the clear-water, turtlegrass-dominated system well documented to be characteristic of the Bay over recent decades. But a reliable historical picture of what Florida Bay was like in its natural, unregulated condition is unavailable. The era of water management began more than 100 years ago, when few scientific data were collected. A major challenge, therefore, is to determine to what extent any reconstruction of Florida Bay to conditions that existed prior to human intervention constitutes an achievable restoration target. The present and future regional environment of which Florida Bay is a part may further constrain an historically-based definition of successful restoration.

Management options and capabilities with regard to restoration are regional in context, and the principal available options relate to the controlling of physical or chemical factors (e.g., manipulation of water deliveries, improved agricultural practices, nutrient removal). In contrast, the success of restoration will be measured in biological terms. For example, the Bay functions as a nursery ground for pink shrimp, as critical habitat for numerous endangered species and as the foundation of the recreational fishing industry throughout South Florida, including the Keys. These and other ecological functions must serve as criteria for evaluating the success of Florida Bay restoration. Thus, interdisciplinary research must link physical and chemical factors to biological processes.

Implicit in the restoration goal is the intention to modify or eliminate anthropogenic processes harmful to the Bay and thus regain the natural ecosystem. Absent from this goal is any intent to modify the Bay's natural function to enhance the prospects of a single species or to maximize economic return. This perspective has guided us in developing the scientific goals and objectives described below.

B. Scientific Goals and Objectives

The science program needed to accomplish successful restoration must be long term and goal oriented and be committed to the integration of emerging results into the management decision-making process. The research program, discussed in detail below, addresses several broadly complementary research objectives. It will provide the basic understanding of the Florida Bay ecosystem so that appropriate plans for restoration can be determined. Specific objectives include the following:

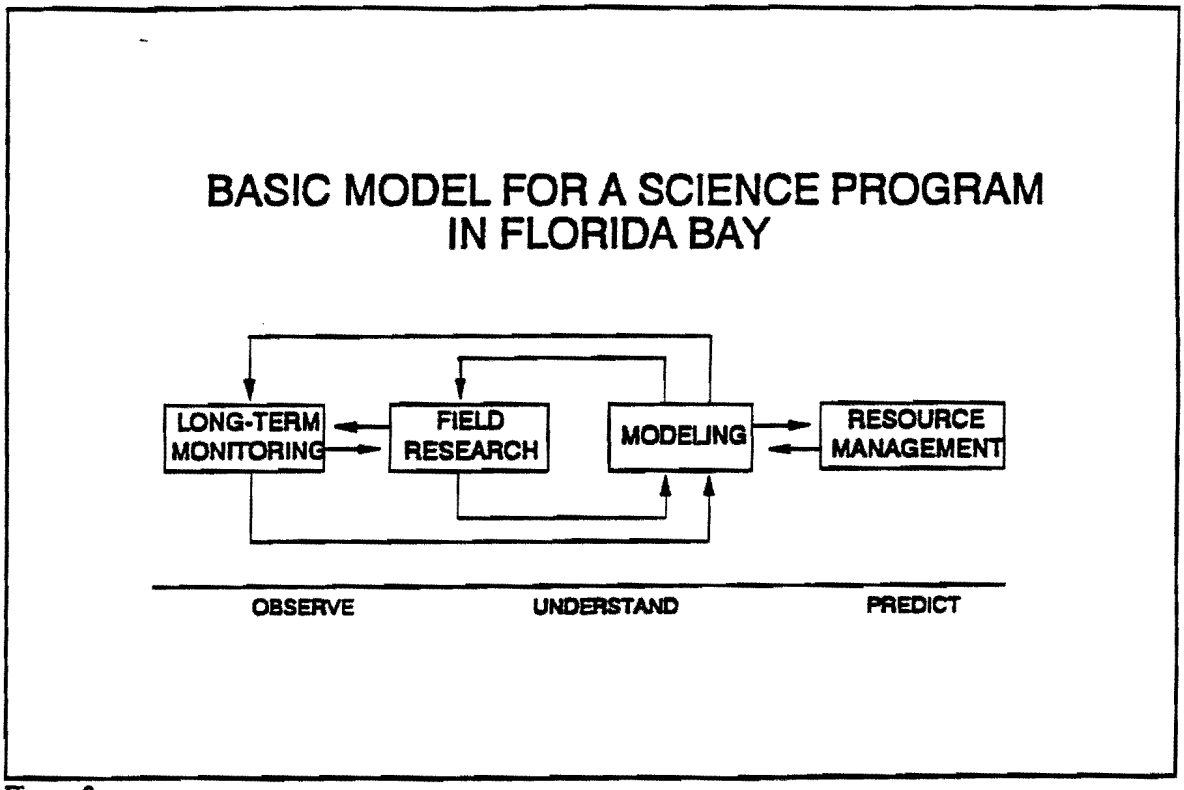


Figure 2

1) Developing an understanding of the condition of Florida Bay prior to man's significantly altering it. This information will help provide an "idealized" target for restoring Florida Bay. Although full restoration may prove impossible, an historical understanding provides a perspective on the extent and effectiveness of management restoration actions.

2) Separating anthropogenically induced changes in Florida Bay from natural system variation. Both natural disturbances (e.g., hurricanes, freezes) and long-term climate processes (drought cycle, sea-level rise) have strongly influenced the structure and function of the Bay. These same processes may mask or exacerbate the effects of anthropogenic forces on the Bay. Therefore, it is essential to understand anthropogenic effects within the context of natural system function and variation.

3) Developing a basic understanding of the ecology of Florida Bay by evaluating alternative hypotheses.

4) Developing the capability to predict the response to perturbation of a subset of species or ecological processes that collectively may be considered indicators of key processes or functions of Florida Bay. Restoration of Florida Bay will require choosing among alternative management actions based on ecosystem responses. Relating the responses of these indicators to potential management alternatives is one way in which an ecological understanding of the Bay becomes a key ingredient in the decision-making processes of agency managers.

C. Research Approach

If a science program is truly to support restoration efforts in Florida Bay, monitoring, research, and modeling elements must be tightly linked, as illustrated in Figure 2. By monitoring, we can track critical ecosystem parameters and support long-term research and modeling efforts by providing baseline data and the means to calibrate and validate models. Further, after management decisions have been made, monitoring data will be used to evaluate the effectiveness of these decisions. Through research, we will develop an understanding of the physical and biological processes regulating Bay ecosystem status by establishing statistical associations, defining and testing conceptual and research models, evaluating cause-and-effect relationships through experimentation, and synthesizing available information. Computer simulations that synthesize our best understanding of the Bay's ecology will be developed to a stage that allows for predictions of system responses to change, hindcasting of historical conditions, and selection of management alternatives. Regular feedback between program elements is needed to yield increasingly reliable computer simulations of the Florida Bay ecosystem for use by management.

D. Linking Research and Resource Management

Modeling is central to the process of linking research findings with resource management decisions that will implement restoration actions. Hydrology models and biological models will be used to develop and select appropriate management alternatives for restoring the Bay. The feasibility of a modeling approach already has been demonstrated. For example, the hydrology of Taylor Slough, at the headwaters of Florida Bay, has been modeled. These models are being used to predict the hydrologic effects of structural or water-delivery modifications of the existing canal system or to predict water conditions in the absence of canals. Biological models should be further developed so that they can predict the response of "representative" species to hydrologic conditions established by water-management alternatives. The current Army Corps of Engineers General Reevaluation Report and Environmental Impact Statement for Canal 111 (C-111 GRR) is one element in a process whereby preferred structural and operational water-management alternatives would be selected and implemented. Analyses of hydrologic and biological monitoring data would allow researchers to evaluate the system's actual response to the resultant hydrologic conditions and would provide the basis for evaluating alternatives and refining models.

Conceptually, this process is iterative. However, the relatively high level of natural variation in the Florida Bay ecosystem; the expected relatively slow response of the flora and fauna of the Bay to changed hydrologic conditions; and the time required to plan, fund, and construct canal structures for water deliveries, argue that restoration of Florida Bay will be a long-term process and that the first iteration must achieve significant restoration benefits. The system's inherent complexity also supports the emphasis in this strategy placed on predictive modeling as the best tactic for testing and evaluating alternatives.

V. MAJOR RESEARCH TOPIC AREAS

Management decisions on restoration must be based on scientific understanding of the Bay, of the changes the Bay has undergone, and of the various natural and anthropogenic processes determining the Bay's present and future status. The following four comprehensive topics describe the major gaps in our present understanding of the Florida Bay ecosystem, our continuing data needs, and the necessity of improving our predictive capacity. Carrying out these specified tasks will provide answers to the questions that need to be answered if restoration is to proceed on a scientifically sound basis. In order to focus in this document on programmatic needs rather than on technical procedures, no attempt was made to provide technical references. Rather, the reader is directed toward the following compilations for further information: the special issue of the Bulletin of Marine Sciences[7] published in 1989, the SWIM Plan for the Everglades[8], and the bibliography of the Science Sub-group report to the Federal Restoration Working Group[9].

A. Water Budgets, Circulation Dynamics, and Salinity

Three interrelated aspects of Florida Bay water budgets and circulation dynamics are considered here, particularly as they relate to salinity patterns and trends in the sub-environments of the Bay. Quantitative knowledge of the mass balance and circulation dynamics of Bay waters is essential to understand the causes of observed biological and chemical patterns within the Bay and their relation to processes outside the Bay.

1. What has been the relationship of surface water and groundwater flows through the Everglades to the salinity of Florida Bay? How has this relationship changed in the past, and how is it expected to change with future management plans?

Under present conditions, the natural flows of fresh water into Florida Bay are much reduced. The Natural System Model indicates that for the 1965-1989 period, as the system is currently managed, less than one half of the "natural" surface-water flow through Taylor Slough was discharged into Florida Bay (32,500 ac-ft/yr versus 82,000 ac-ft/yr). The flow of Shark River also seems to have been significantly reduced from "natural" conditions, although flows during 1991 and 1992 were nearly three times the annual average for the 1980s. How changes in freshwater delivery through the Shark River Slough (whose flow is an order of magnitude greater in volume than the natural flow through Taylor Slough) have affected Florida Bay is not well known.

Salinity records, anecdotal evidence, and predictive models linking groundwater levels in northern Taylor Slough to salinity in Little Madeira and Joe bays provide evidence that salinities in northeastern Florida Bay have increased as a result of reductions in freshwater inflow. Salinities have been elevated since at least the mid-1950s and on occasion have been markedly hypersaline (to 70 ppt). The relationship between salinity levels in the open central Bay and

reductions in freshwater discharge is unclear. Discontinuous salinity measurements made in the more open central and western Florida Bay from 1955 through 1990 show no obvious changes in salinity, although hypersaline conditions have characterized the northcentral and northwestern Bay at least since the mid-1950s. The historical record, however, indicates that large increases in freshwater inflow during extended periods of heavy rainfall (e.g., during 1983) can eliminate hypersaline conditions in the eastern and central Bay, whereas hypersaline conditions developed during dry years, even before most of the flow through Taylor Slough was diverted down the C-111 canal.

Key Research Needs

The goal of the physical oceanographic research and modeling effort will be to collect data and to develop models sufficient to predict, both for the Bay as a whole and for its major subbasins, the influence of varying freshwater inflow and precipitation on circulation dynamics and salinity patterns.

Specific Tasks

i. Determine the rates and effects on water quality of freshwater flows through the Taylor Slough rivers and channels, canals and adjacent panhandle area into Florida Bay. The spatial and temporal variation across this transition zone must be quantified for a range of wet and dry hydrologic regimes. A sampling system is needed so that episodic events and low flow conditions are accurately characterized. Salinity/runoff relationships must be developed so that effects on inflow rates of differing water-delivery policies can be quantitatively predicted.

ii. Quantify the importance of groundwater as part of freshwater input and as a factor influencing water quality in Florida Bay. Groundwater contributions to Florida Bay are one of the most poorly known components of the water budget. Because of the difficulty of measuring it, groundwater is often estimated fromhydrolo gic models. Some field measurements are essential to calibrate and verify models. Estimates of flows through he Buttonwood Ridge and other components of the mangrove fringe and associated boundary areas in the southernmost mainland are particularly critical.

iii. Determine the linkage between Shark River Slough discharges and Florida Bay. Temperature, salinity, and current measurements in the tributaries of the Slough and perhaps tracer studies of nearshore currents between the main Shark River estuaries, Cape Sable, Sandy Key Basin, and the Flamingo area are needed to permit quantification of the net flux of water and salinity into the Florida Bay. Data are needed over several annual hydrologic cycles in order to understand seasonal and interannual effects.

iv. Determine the spatial pattern of salinity in Florida Bay and its relationship to freshwater inflow and climatic variation. Consideration should be given to supplementing the existing salinity-sensor network with automated salinity sensors and/or augmenting these measurements with micro-radiometry-based remote sensing of surface salinity when operational systems become available. Efforts should also be made to determine historical salinity patterns in Florida Bay.

v. Determine evaporation rates from the Bay and the canals and characterize their temporal and spatial variations.

vi. Improve monitoring of rainfall. The precision of traditional rain gauges is poor, but their performance could be improved by judicious use of radar- and acoustic-based measurement methods.

vii. Develop a circulation dynamics model for Florida Bay. The model should incorporate existing model structures from other water bodies as much as possible and be capable of simulating circulation and transport across the Bay as a whole, both within the major sub-environments and within local basins. Development of the model should proceed cooperatively with ecological modeling efforts so that model structure and outputs are accessible for addressing questions on the movement, recruitment, and distribution of marine organisms and on the transport, accumulation, and cycling of nutrients and contaminants. Adequate answers to these questions may eventually require a three-dimensional model, but until that is demonstrated, a two-dimensional model will suffice.

viii. Integrate circulation models of Florida Bay with larger-scale physical oceanographic, hydrological, and meteorological models that provide the Bay model with its boundary conditions and forcing functions. Erosion and sea level rise are two important continuing processes that must be explicitly tested in a complete model. A mesoscale meteorological model that could improve prediction of precipitation intensity and distribution would be invaluable to both circulation and hydrological modeling.

2. What is the effect of the relative lack of storms over the past three decades on the buildup of sediments, nutrients, and organic material in the Bay?

Hurricanes are believed to resuspend and transport sediments and organic detritus out of bays. Few, if any, hurricanes have significantly affected Florida Bay since 1965. In the absence of these erosional events, production of sediments and their trapping by seagrasses and mangroves could reduce water circulation, thereby affecting salinity distribution, water temperature, nutrient supply, habitat, and movement of marine organisms.

Quantitative evidence on the effects of storms is lacking, but qualitative observations

suggest that the reduced occurrence of major storms has resulted in significant accumulation of calcareous muds and entrained nutrients.

Key Research Needs

Because Florida Bay is a shallow-water system, sediment dynamics are particularly important. Much of the primary production in the Bay is benthic, and resuspended sediments can markedly reduce photosynthetic potential. The fine-grained, shallow sediments are susceptible to physical and chemical alteration by the forces of weather and biological and human activity. Despite the importance of sediments, however, information on their dynamics, composition, and spatial patterning is insufficient for reaching a quantitative understanding of their role in the changing conditions of Florida Bay.

Specific Tasks

i. The bottom topography of the Bay has not been systematically examined in three decades. Plotting the bottom contours on a grid fine enough to delineate the basins and their interconnections is essential both to document changes in water depth and to supply information for circulation modeling. Whether this can be done by compiling existing data or whether extensive new measurements are required cannot be determined in advance. The answer may depend on the degree of sensitivity of various models to water depth. The scale of the bathymetry data should be appropriate to circulation modeling requirements.

ii. Determine the main components of the sediment budget for Florida Bay, including exchanges with connected waterbodies, inputs from the mainland, and accumulation within selected subbasins.

iii. Determine the physical and chemical composition of the sediments, the pattern of composition throughout the Bay, and the variability in composition over hydrologic cycles and in relation to storm events.

iv. Determine the historical pattern of sediment accumulation and composition. Bay sediments should be cored following standard procedures. Cores should be subjected to radioisotope dating, stable isotopic analysis, and any other physical or chemical analyses deemed to be helpful in reconstructing historical Bay conditions.

3. What have been the effects in Florida Bay of increased residence time of water caused by restricted water flow through channels between the Keys, shoaling, and reduced freshwater inflows?

Little is known about the residence time of water within Florida Bay, although a decrease in the flushing rate could have widespread consequences to this ecosystem. As a result of land-filling along the Keys, an increase in residence time is likely to have occurred. Mudbank shoaling may also have further decreased flushing of isolated basins in the Bay. But the extent to which flushing may have been decreased by channel constriction or shoaling is unknown. Except for the regions of the northeastern Bay directly affected by the Taylor Slough discharge, reductions of freshwater flows may have had little impact on the flushing rate of the Bay. Salinity could have increased through more evaporative concentration of Bay water, especially because freshwater inputs have decreased. Greater stagnation could also increase temperature extremes, increase concentrations of plant nutrients, and disrupt recruitment of planktonic fish and invertebrate larvae.

If one assumes that flow through Taylor Slough has been reduced by 50,000 ac-ft/yr and that the average depth of the Bay is about 1 m, the total diverted flow during a full year would, on the average, be sufficient to replace only about 10% of the volume of the Bay. Tidal and wind-driven flows surely exchange far more of the Bay's volume, probably on the scale of days. Also, because the Bay is shallow and vertically well mixed, there should be no appreciable gravity flows of the type found in deeper, stratified estuaries by which the flushing effect of freshwater inputs is greatly magnified.

Specific Tasks

i. Determine the effect on circulation of shoaling caused by sediment accretion on the mudbanks. This could have a very great effect on the flushing rates for basins in the central and eastern Bay, but this effect has not been measured or estimated. A program of field-data collection in selected subbasins is needed. This program should quantify both incremental processes and mass movements that may accompany episodic climatic events. Since the data are valuable for circulation modeling, compatibility with models is important.

ii. Determine the relative importance of tides, winds, and altered freshwater inflows on flushing rates and exchanges with adjacent waterbodies. Data are needed on time scales of days, months, and years across a range of wet and dry cycles to adequately parameterize circulation models.

B. Water quality and nutrient cycling

1. What are the sources, quantities, and ecological effects of "external" nutrients introduced into Florida Bay?

The exchange of nutrients between Florida Bay and adjacent regions ("external" dynamics) and the cycling of nutrients within Florida Bay ("internal" dynamics) underpin the entire Bay's ecological structure and function, the occurrence of algal blooms, seagrass mass mortality, and the sustenance of critical species. We currently have little understanding of the rates of these

processes or the mechanisms that control the rates. Furthermore, we have little understanding of how these dynamics have naturally varied in the past or how human activities have affected them.

Algal blooms in the Bay appear to be similar to blooms caused by anthropogenic nutrient loading, which has been observed in estuaries throughout the world. However, the sources of the nutrients that sustain Florida Bay's blooms are unknown. Although it is likely that the blooms are in part sustained by nutrients derived from decomposing seagrass detritus resulting from seagrass die-back events, the blooms may also depend upon the supply of external nutrients from agriculture, fertilizer mining, or sewage in the Keys. Changes in the input of nutrients to the Bay may also result indirectly from altered hydrology; changes in freshwater flow and salinity intrusion may have reduced the retention of nutrients within the Everglades and mangrove ecosystems. Finally, the Bay may appear eutrophic not because the total inflow of nutrients has increased, but because the residence time of source waters with high concentrations of nutrients has increased with diminished flushing rates (see above), or because internal sinks of nutrients have decreased.

Understanding the exchange of nutrients between Florida Bay and adjacent regions requires an integrated effort to 1) measure the flux of nutrients across the Bay's boundaries; 2) characterize the physical, chemical, and ecological mechanisms that regulate these fluxes; and 3) integrate this information into a regional landscape model of nutrient transport and transformation. The major boundaries that must be considered are between Florida Bay and the atmosphere, the northern coast, the Gulf of Mexico, and the Florida Keys. Thus, an effort to understand the nutrient dynamics of the Bay must be integrated with efforts to accurately describe surface and groundwater inflows from the Florida mainland, the exchange of Bay water with the Gulf of Mexico and through passes in the Florida Keys, and atmospheric deposition rates.

Key research needs

Atmospheric deposition of nutrients is known to be a significant nutrient source in many coastal ecosystems and may be particularly important in Florida Bay because the Bay appears to have been oligotrophic throughout much of its history and is surrounded by relatively low-nutrient wetlands and water bodies. A key research need is to determine deposition rates and atmospheric nutrient sources.

Specific Tasks

i. Measure the deposition of wet and dry nutrients into the Bay.

ii. If these inputs are important, relative to other inputs, determine the sources of these nutrients and estimate their historical variability.

Additional research is needed to determine the exchanges of nutrients between the Bay and the Gulf of Mexico and the degree to which these exchanges have been altered by human

activity. The Gulf of Mexico may be an important nutrient source for the Bay for several reasons. First, there appears to be a net advection of water from the Gulf into the northwestern Bay. Second, the Gulf ecosystem, like most marine ecosystems, is probably N limited, and thus has a small "excess" of P, relative to N. Third, the Florida fertilizer industry may enrich Gulf waters. Fourth, organic P flows into the Gulf from the western Everglades and the dense mangroves along the southwest Florida coast. Although this water has a high N:P ratio, the absolute quantity of organic P delivered to the Bay may nevertheless be significant. This N source may, furthermore, stimulate algal blooms and benthic macrophytes west of the Bay, where N limitation may be more prevalent than in the Bay.

Specific Tasks

i. Continue and extend water-quality monitoring in the western Bay and southwestern Florida coastal waters on both a regular schedule and on an event basis, so that exchanges during storm events can be determined.

ii. Monitor the distribution, transport, and nutrient demands of algae along the western Bay boundary.

iii. If budgets suggest that Gulf waters are an important nutrient source, investigate the import and export of nutrients through mangrove ecosystems in representative sectors of the southwest Florida coast and estimate their historical variability (see mangrove subsection below).

Determining the exchange of nutrients between the northern Bay and the South Florida wetlands and the degree to which these exchanges have been altered by human activity is also needed. No measurements have been made of the flux of organic or inorganic nutrients across the salinity transition zone of the coastline. The rapid appearance and disappearance of dense macroalgal clumps in streams that feed into the northeastern Bay suggest that the export of nutrients from this zone may at least be locally important. The N:P ratio of this source is probably high, and the mechanisms altering this ratio have not been studied in the transition zone.

Specific Tasks

i. Estimate nutrient flux by measuring surface and groundwater flows into the Bay and their nutrient concentrations across the entire northern coast.

ii. Continue water-quality monitoring in the northern Bay.

Another key to understanding the inflow of nutrients to the Bay from both the southwest and south Florida coasts is understanding the ecology and biogeochemistry of mangrove ecosystems. Along with the Everglades marshes, mangroves are a biological filter through which much of the freshwater inflow passes before reaching the Bay. Despite low P inputs from the Everglades to the mangrove forests, the mangrove forests are highly productive, and their

standing stock and litter represent a potential nutrient source. A large export of nutrients from these systems either on a regular (e.g., seasonal) or episodic basis (e.g., freezes and hurricanes) is possible. Furthermore, the extent to which the retention or release of nutrients by coastal wetlands and mangroves has changed in response to human activities and climate change (e.g., increased intrusion of seawater resulting from sea-level rise and freshwater diversion) is unknown.

Specific Tasks

i. Measure water flow and the import and export of dissolved and particulate nutrients at selected sites, especially after episodic disturbances.

ii. Investigate the sources of nutrients for mangrove trees (marine, inland, sediments).

iii. Investigate the effects of altered salinity regimes upon nutrient dynamics within mangrove and marsh systems, including effects on decomposition, mobilization from, and immobilization in sediments.

iv. Assess recent changes in the distribution and biomass of mangroves along South Florida coasts (see section C below).

v. From Bay sediment cores, assess changes in the historical accumulation of organic matter derived from mangroves and other terrestrial sources.

Research is needed to determine nutrient fluxes through passes in the Keys and the input of nutrients to the Bay from sewage in the Keys. Sewage effluent from the Keys is known to have caused localized eutrophication. The regional importance of this nutrient source is not known. This may be of more direct significance to the Florida Keys National Marine Sanctuary. Researchers sponsored by the Sanctuary should be directed to undertake the following in collaboration with the Florida Bay program.

Specific Tasks

i. Monitor the flow of water and organic and inorganic nutrients through the Keys' passes.

ii. Estimate the input of anthropogenic nutrients from the Keys.

2. What are the rates of nutrient exchange between the sediment and water column within Florida Bay, and what controls the magnitude and direction of these fluxes?

Because of Florida Bay's shallow depth and the carbonate composition of its sediments,

the internal dynamics of nutrients within the Bay are regulated by sedimentary processes. Given the Bay's shallow depth and historical clarity, seagrass primary production has been considered the basis of overall Bay productivity. However, the shallow depth of the Bay also results in high resuspension rates for unconsolidated sediments (see section C). Suspended sediments not only decrease light penetration through the water, but also scavenge particle-reactive solutes such as inorganic phosphates from the water. The carbonate composition of these sedimentary particles is important because the particles have the potential to bind inorganic P under both oxic and anoxic conditions. Thus, apparent P limitation in the Bay may be due not to biological utilization but to loss to the sediments. We need to know if mechanisms exist whereby this P can be released.

One such mechanism may involve the normal physiological activities in the seagrass rhizosphere. It is possible that seagrasses exude organic acids or sustain a microbial consortium that mobilizes phosphorous. Thalassia may be particularly important in this regard because this species has a deep and extensive root system. It has thrived in recent decades in waters with salinities that were higher than those found before the water diversion from the Everglades (see above); as a result P mobilization from the sediment may have also been accelerated.

Other mechanisms that may alter the extent to which P is bound to or released from carbonate particles may involve the surface chemistry of carbonate particles, in particular their organic coatings. Seagrass and mangrove die-offs and wetland perturbation may have altered organic inputs into the Bay. Salinity itself may play a direct role because ionic strength is an important variable affecting surface reactions.

Key Research Needs

Key research needs include estimating rates of benthic nutrient fluxes at various sites in order to accurately estimate flux for the Bay as a whole, assessing the importance of different mechanisms upon the mobility of nutrients bound in sediments, and assessing how the internal nutrient cycles of Florida Bay may have changed during past decades and centuries.

Specific Tasks

i. Measure net fluxes in benthic chambers and from sediment cores.

ii. Measure rates of detrital decomposition in healthy and declining seagrass stands.

iii. Investigate the processes by which seagrasses, particularly Thalassia, assimilate nutrients from sediments and assess the effect of environmental (e.g., light, temperature, and salinity) conditions upon observed rates.

iv. Investigate the chemical and microbial processes that mobilize or immobilize nutrients in the sediments.

v. Develop a model of the benthic subsystem that includes seagrass populations and all the nutrient pools and pathways potentially significant to the overall nutrient cycle.

vi. Determine the contribution of nutrients from tidal pumping nutrient-rich subsurface water from the permeable limestone floor to the water column.

vii. Obtain and date sediment cores; estimate rates of sediment and nutrient accumulation and their temporal variation.

3. What are the rates of nutrient assimilation by phytoplankton in the Bay, and what limits the growth of the phytoplankton assemblage?

Pelagic primary production has increased in relative importance in much of the Bay. With continued seagrass die-off, sediment resuspension has increased, thus increasing light extinction by inorganic particles. The situation may be perpetuated by a feedback loop whereby dense microalgal blooms inhibit seagrass recovery by absorbing light and thereby increase sediment resuspension, furthering their own competitive advantage. Pelagic dynamics that have been heretofore ignored now need to be studied.

Key Research Needs

Key research needs include developing basic information on the phytoplankton ecology of the Bay and assessing the importance of factors other than nutrients upon the development and maintenance of algal blooms.

Specific Tasks

i. Measure the distribution, biomass, productivity, and composition of the phytoplankton community.

ii. Monitor light distributions in the water column.

iii. Determine photosynthesis versus light extinction curves for the dominant phytoplankton species.

iv. Measure nutrient uptake kinetics of the dominant phytoplankton species and conduct experiments to study phytoplankton nutrient limitations.

v. Measure zooplankton biomass and grazing rate.

vi. Measure benthic filter feeder biomass and grazing rate.

vii. Estimate the effect of sediment resuspension upon light and nutrient availability in the water column.

viii. Use the sedimentary record to determine whether extensive phytoplankton blooms occurred in the past and if so under what conditions.

ix. Develop a model of water column processes that is coupled to the benthic model (and sediments) and that incorporates both pelagic nutrient dynamics and grazing losses.

4. What are the sources, quantities, and effects of toxic pollutants introduced into the Florida Bay ecosystem?

Pollutants are a common problem in coastal ecosystems, but given the relative isolation of Florida Bay from extensive municipal and industrial development, toxic pollutant inputs from sources other than local agriculture should be minimal. However, we currently have little information on inputs, pathways, or effects of toxic pollutants in the Bay. Because it is likely that management actions taken to restore freshwater inputs to the Bay will also affect pollutant dynamics, we need to establish a monitoring program before these changes are made.

Mercury is a pollutant of special concern. It is a human health hazard because of its toxicity, persistence, and the extent to which it bioaccumulates in tissues and biomagnifies through the food chain. It has also been found at high levels in the Everglades biota, including fish in northeastern Florida Bay. Thus, mercury contamination in the Bay may be increasing.

The other major group of toxic pollutants of particular concern are synthetic organic compounds that are used as pesticides both in mosquito control and in South Florida agriculture.

Key Research Needs

Key research needs include determining the extent, pathways, and history of mercury contamination in the Bay; determining the flux of dissolved and absorbed toxic organics into the Bay; and determining the atmospheric flux of pesticides into the Bay. Monitoring mercury concentrations in selected Florida Bay biota is a prudent first step given the problems already evident in the Everglades. Monitoring all or most of the toxic organics used in Florida agriculture is unnecessary. Rather, attention should be paid to pesticides that are used in large quantities, are mobile in surface water or groundwater, are relatively persistent, and are known to have significant ecological effects. A Contaminants Advisory Committee should be established to determine which compounds warrant study.

The main concern in determining atmospheric flux is direct aerial input because pesticides are extensively used for mosquito control in Dade and Monroe counties. This may have a local effect at the time of application. Larval crustaceans are particularly sensitive to such

chemicals, and thus, the timing of these doses and their distribution in the Bay warrant further study.

Specific Tasks

i. Monitor tissue concentrations in fish and organisms from upper trophic levels, e.g., crocodile eggs.

ii. Monitor water column mercury concentrations and chemical forms in water entering the Bay and at selected stations within the Bay.

iii. Measure atmospheric mercury inputs.

iv. Measure the historical record of mercury accumulation in the Bay from sediments, peat, or corals.

v. Monitor mercury concentrations in canals and other surface water and groundwater.

vi. Monitor water and sediment mercury concentrations at a set of Bay stations.

vii. Monitor mercury concentrations in those fauna that may integrate the variability of exposure in the Bay (e.g., filter-feeding bivalves), those species that may have high body burdens (e.g., from upper trophic levels or those with an especially high fat content), and those species that may be particularly sensitive to pesticides (e.g., the osprey).

viii. Monitor the time, amount, and extent of pesticide application (including information on not only the "active" compounds but the associated solvents) and establish a centrally accessible data base.

ix. Relate actual pesticide application to potentially critical areas and periods within the Bay, considering the life history and recruitment of key species.

x. Monitor the body burden of the pesticide compounds applied to the larvae, juveniles and adults of key species (e.g., pink shrimp).

xi. Perform special studies to assess specific pesticide application events.

5. What is the cause of turbidity in the Bay, and what is its effect on Bay water quality?

Increased turbidity is the most conspicuous change in the Bay since 1987. Declining water clarity has the potential to shift Florida Bay away from a system dominated by benthic

primary production towards one dominated by water-column productivity. This critical area needs to be researched further.

Specific Tasks

i. Determine biological components of turbidity.

ii. Determine contribution of resuspended sediments to turbidity and determine how suspended sediments relate to sediment transport, erosion, and deposition.

C. Seagrass, Mangrove, and Hardbottom Habitats

The three major habitat types in Florida Bay are discussed here. Each has undergone significant change, particularly seagrass meadows. Historically, seagrasses have been the dominant primary producers in Florida Bay. In addition they structure the benthic habitats by providing refuge to important consumer species in their vulnerable early stages and by consolidating otherwise readily resuspended carbonate sediments. Recent changes in seagrass distribution and abundance throughout Florida Bay constitute a major shift in the functional dynamics of the ecosystem. The resultant effects on organisms, food chains, processes, and the Bay as a whole are of major concern for all three habitat types.

1. What environmental factors explain the observed distribution of seagrasses within the Bay and caused the recent die-off?

Reduced freshwater flow into Florida Bay resulting from drought and diversion of upland runoff is thought to have caused significant increases in average salinities in the interior basins of Florida Bay. The higher salinities have allowed Thalassia testudinum beds in the north-central and western Bay to develop very high densities and biomass in basins that historically supported a more diverse, more typically estuarine seagrass assemblage (e.g., Halodule, Ruppia, and Thalassia).

Nonetheless, seagrass populations of Florida Bay appeared to be thriving as late as 1984. Leaf defoliation of bank-top seagrasses and seagrass die-off was observed during the summer of 1987. Seagrass die-off spread rapidly, affecting primarily but not exclusively the dense beds of north-central and western Florida Bay. It is speculated that the shallow waters and restricted circulation of Florida Bay, coupled with diminished freshwater flow from the Everglades and the exaggerated near monospecificity attained under these conditions, amplified the effects of natural temperature and salinity variations and thus caused large-scale die-offs.

Key Research Needs

The first step is to fully understand the causes (both natural and anthropogenic) of the

observed changes and the relationships bet ween these factors. Detailed physiological, ecological, and demographic information is essential if we are to develop a predictive capability. Estimating future changes in seagrass distribution, abundance, and dynamics is an essential component of the scientific basis for restoration management.

Specific Tasks

i. Determine current seagrass species distributions, abundances, and biomasses to assess possible large-scale spatial changes that have taken place since the 1983-84 survey. Incorporate these data into a GIS database.

ii. Determine the effects of salinity, light, temperature, and nutrient concentration upon seagrass species distribution and productivity, population growth, and succession by conducting controlled factorial laboratory and field/mesocosm experiments. Light compensation points and limiting nutrient dynamics need to be determined for growth in the carbonaceous (and high-sulfide) sediments of Florida Bay. The effects of persistently reduced light on seagrass species distribution need to be assessed.

iii. Conduct surveys of benthic and epiphytic macroalgae to assess relative eutrophication of the system and possible competitive effects upon the seagrasses.

iv. Determine the age structure and mortality and reproduction patterns in Thalassia, Halodule, and Ruppia subpopulations. The distribution of Thalassia rhizomes in areas currently unvegetated or vegetated by other seagrasses should be used to map past mortality events.

v. Monitor productivity, plastochrone interval, and shoot-specific leaf area in Thalassia; these characteristics provide indications of physiological status of Thalassia and are indicative of environmental stress. Determine whether these characteristics are useful indicators in the other seagrass species.

vi. Determine the etiology of seagrass die-off in situ in Florida Bay. The patchy distribution patterns, density dependence, spread rates, and leaf necroses associated with die-off of Thalassia suggest the involvement of a pathogenic organism. Given the high concentrations of dissolved sulfide in sediment porewater, hypoxic stress of subterranean Thalassia tissue also may play a role. Although it may be impossible to determine with any certainty what precipitated the original die-off event, it is still important to determine the proximal causes of die-off if we are to anticipate future events.

vii. Determine the influence that increased epiphytism, decreased water clarity due to resuspension of unvegetated sediments, and increased phytoplankton concentrations have upon seagrass recolonization and population recovery rates.

viii. Develop spatially coupled physical-biological models linking experimentally verified causes of die-off to the distribution of seagrasses throughout Florida Bay in order to evaluate recovery potential and predict the effects of restoration efforts. Verify these models through a continuing monitoring program.

2. What environmental factors explain the pattern of mangrove die-back within the Florida Bay ecosystem?

Mangrove communities in South Florida are potentially affected by a number of anthropogenic and natural factors whose relative significances are not well known. These may act synergistically to significantly change the mangrove community. The importance of the transition zone and island mangrove communities to the Bay ecosystem dictates that greater attention be paid to their physiological ecology, growth, and reproductive biology.

Hurricane Andrew severely damaged more than 70,000 acres of mature mangrove forest on the west coast of Everglades National Park. Winter freezes in 1983 and 1989 also damaged large areas of mainland mangrove communities, but no quantitative damage assessment has been made. Reduction in freshwater delivery to the southern margin of the mainland and Florida Bay also has been suggested as a factor in mangrove mortality. An increasing problem is associated with the exotic tree Schinus terebinthifolius, which has displaced mangroves in some areas of the Gulf coast mangrove forest.

The impact of the 1989 freeze may have been exacerbated by low water levels in the Everglades, which in turn resulted from drought and hydroperiod manipulations. Although hurricanes have been an historical factor in the evolution of South Florida mangrove ecosystems, dispersal and establishment of alien plant species in mangrove communities is facilitated by hurricanes. Mangrove communities, possibly more than any other community, will be vulnerable to changes in tidal inundation patterns associated with eustatic sea-level rise and the accelerated sea-level rise forecast in global-climate-change scenarios.

Key Research Needs

A combination of monitoring and experimentation will be required to elucidate the key mechanisms that could change the mangrove communities of Florida Bay, the extent of present mortality, and the impact of this upon the Bay ecosystem.

Specific Tasks

i. Monitor mangrove community composition and coverage on the South Florida mainland and islands in Florida Bay. Quantify changes for the entire area on a multi-year schedule, and sample smaller areas more frequently. Analyze available aerial photographs to determine past changes. Incorporate all data into a GIS-database.

ii. Determine the effects of tidal inundation patterns, freshwater-flow alteration and nutrient availability upon mangrove growth, physiology, and reproduction.

iii. Determine the relationship of past, present, and future freshwater-flow patterns to the extent, vigor, and functional integrity of mangrove communities within the mainland region of Everglades National Park and on the Florida Bay keys.

iv. Continue assessment of Hurricane Andrew's impacts on mangroves, with particular emphasis on recovery patterns and invasion by exotic plant species.

v. Model mangrove population dynamics in Florida Bay and adjacent mainland areas based upon the above data [i-iv].

vi. Determine the significance of mangrove habitats, production, and nutrient cycling to the Florida Bay ecosystem by studying food-web and habitat utilization, and incorporate the mangrove community into an overall ecosystem model (see section B).

vii. Monitor salinity of hypersaline groundwater on islands in relation to mangrove die-off.

3. What has been the cause and consequence of sponge die-off and the subsequent alteration of hardbottom communities?

Mass mortality of sponges has occurred throughout large areas of the south-central and southwestern portions of Florida Bay. Circumstantial evidence links sponge mortality to the presence of the algal bloom that has persisted in that region; however, no experimental confirmation of that linkage exists. Sponges are a major structural component of Florida Bay hardbottom communities and may contribute to water clarity through filtration. Little is known about the ecological implications of their loss.

Specific Tasks

i. Determine the mechanism for sponge mortality. Experimentally verify the linkage between phytoplankton blooms and sponge mortality using cultures of dominant bloom species in controlled laboratory experiments. Transplant sponges to bloom areas to evaluate susceptibility of individual species. Include cellular analysis of sponges.

ii. Incorporate hardbottom communities into a biological monitoring program. The initial goals of such a program will be to evaluate variations in abundance of the structural components of hardbottom habitat across Florida Bay and use these data to experimentally

test the effects of change in this community and the community's relationship to living resources.

D. Living Resources

The living resources of the Bay include, as a general category, those organisms specially recognized because of the species' ecological, regulatory, conservation, and/or economic value. To varying degrees, many of these have exhibited population trends suggesting that Florida Bay's capacity to support them is declining. Other species, however, have not been studied enough to evaluate trends.

1. Has recruitment into Florida Bay been affected by habitat changes in Florida Bay, and have altered environmental conditions affected growth and survival of animals in Florida Bay?

The interactions of known and suspected environmental changes such as salinity variations, current modifications, nutrient or pollution inputs, freshwater input, algal blooms, grass die-offs, and sponge die-offs are suspected to affect the distribution and abundance of living resources. A given taxon's sensitivity to any of these factors may differ with life history, trophic position, and length of exposure to Florida Bay water (e.g., whether the entire life cycle or just a part is spent within Florida Bay). Often the most sensitive stages are the recruit and the juvenile stages. Therefore, the study of recruits and juveniles can provide valuable predictive information about subsequent overall population changes. Along with community-level studies, a suite of critical or indicator species will be selected as the focus of these population level and physiological studies.

Key research needs

A combination of monitoring, research, and modeling is required to link habitat change to shifts in living resources. The key elements of each are defined below.

Specific Tasks

i. Develop a baywide faunal monitoring program in the major sub-environments of the Bay. Design surveys to establish correlations with other measured factors that then will be tested experimentally for causal relationships. Compare results with past studies in retrospective analyses. Critical observations should include but not be limited to the following:

- the age and/or size of animals - e.g., detection of shifts in abundance from one size- or age-class to another will lead to the testing of hypotheses relating population changes to ecosystem changes.

- health and condition of organisms.

- reproductive condition or stage.

Additional actions needed to test specific hypotheses may include sampling algal blooms within and beyond Florida Bay and sampling across gradients of salinity, latitude, and distance from channels between the keys.

The monitoring program must be of sufficient duration to permit meaningful time-series analyses of trends and restoration efforts. Special attention is needed on the following taxa:

- Pink and Caridean Shrimp - because of their utilization of grassbeds as a nursery area.

- Spiny Lobster - because algal blooms depleted the number of sponge shelters for juvenile lobster.

- Fishes - because they may be quantitatively censused with nets in bloom waters. Community-level analyses of fish assemblages may provide a means to measure changes in habitat.

- Mollusks - because many are indicative of salinity and because shell accumulations permit comparisons of compositional change over time.

ii. Conduct comprehensive life-history studies of selected species for basic information such as levels of recruitment and transport of recruits, critical shelter and forage habitats, and how habitat use changes with environmental modification.

iii. Conduct manipulative field experiments testing the impacts of change in critical habitats on distribution, abundance, and survival of critical life stages.

iv. Couple the above field work with laboratory-based physiological and behavioral experiments investigating the tolerances and preferences of fishes to conditions that exist in Florida Bay or might exist under proposed management strategies.

v. Develop models linking experimental data to information on life histories, habitat change, and changes in the physical environment that will emerge from research described in other areas of this plan. These models should be sufficiently detailed to evaluate causes of changing abundance patterns, if any, and sufficiently broad to evaluate any changes that occur on a regional scale. Model outputs need

to be regularly verified by the monitoring and experimental approaches described above.

2. Has habitat degradation or loss caused a reduction in fishery productivity in the Bay?

Degradation of Bay habitats has been blamed for causing declines in fishery resources as reflected in fishery-dependent data. However, these data encompass only adult life-history stages. Although these data are sufficient indicators of fisheries productivity at a given time, they are subject to biases due to gear type, angler behavior, and fishing regulations. Furthermore, the fact that commercial fishing has been prohibited in the NPS portion of the Bay since 1985 further confounds data interpretation. In short, the causes of observed declines have not been identified with any certainty. Some fishery-independent sampling has been conducted in the Bay and adjacent waters but only to a limited areal and temporal extent. Collectively these data may provide some basis for comparison with results from future surveys.

Key Research Needs

Detailed information is needed on the quality and quantity of available habitat and species' habitat preferences. Much of this information will be obtained from research and monitoring efforts described earlier. Fisheries landings data, collected since the 1960's, will provide an initial basis for research on impacts upon fisheries productivity and can guide additional data collection allowing more rigorous determination of cause and effect relationships. The direct impact of habitat change or degradation can be ascertained by analyzing specific tissues and forage items that accumulate toxins and pollutants. Elucidating the physiological impact on selected species of such toxins will require laboratory studies.

Specific Tasks

i. Collect unbiased information on all the life-history stages of selected indicator species. This information is best derived by supplementing fishery- dependent sampling with fishery-independent sampling. Fishery-independent sampling should be directed at specific life-history stages and should be habitat based.

ii. Focus on habitat-based research, particularly the structure and function of each habitat type. Research that defines the linkage between seagrass and mangrove habitats and the effects on fisheries of changing benthic vegetation is critical. Specifically, pre- and post-die-off seagrass and mangrove faunal community composition must be quantified.

iii. To address the decline in the pink shrimp fishery, develop a model that relates cohorts on nursery grounds to cohorts in the Tortugas fishery landings.

iv. Attempt to measure the impacts of habitat change via tissue analysis and

stomach contents analyses. For some species, tissues wi'l need to be examined to define the overall health of a particular species within the Bay.

v. Conduct complementary laboratory physiological research on early life- history stages of key species to evaluate changes in habitat on coastal resources.

3. Have environmental and habitat changes in the Bay affected the distribution and reproductive success of upper- trophic-level consumers?

Everglades National Park and Florida Bay are important foraging and rookery habitats for many species of wading birds, shore birds, and top-level predatory birds such as eagles, ospreys, and brown pelicans. In addition, the entire U.S. population of the Great White Heron resides in southern Florida, and about 65% of the population nests on fringing mangroves and mangrove islands in Florida Bay. Declines in many species, particularly wading birds and ospreys, have been measured over the past several years. One possible explanation for these population declines is that they are the direct result of declines in the quality of resources available.

Four species of marine turtles have been reported to occur in Florida Bay; loggerhead and green turtles are regular residents. Kemp's ridley and the hawksbill turtle are present but less common. Adult male loggerheads are particularly common, and the Bay may serve as adult resident habitat or an important migratory route for the western Atlantic loggerhead reproductive contingent. Seagrass communities provide forage for turtles, and seagrass community diversity has been shown to be significant in providing sufficient nutrition for the herbivorous green turtle. Fibropapilloma disease affects 70% of all captured green turtles and has been documented in more loggerheads within South Florida than ever reported from any other geographic location. Although the etiology of the fibropapilloma disease is unknown, one hypothesis is that environmental contaminants may weaken the turtle's immune system.

Bottlenosed dolphin are regular residents and users of Florida Bay. Although dolphins consume Bay finfish, the relative importance of this habitat to dolphins in the southeastern U.S. is unknown.

Manatees utilize the Bay and adjacent waters on a seasonal basis and their numbers within the Bay have been well documented. Changes in the distribution of manatees in the Bay over time suggest a decline in use of the northern Bay, although historically, the northeastern portion was the most important area of the Bay for manatees. Proposed changes in freshwater inflow may have direct impacts on the benthic vegetation, which is critical forage for manatees. How these changes in vegetation have affected the distribution and abundance of manatees in the Bay is poorly understood.

The endangered American crocodile is found exclusively in South Florida from the southern portion of Biscayne Bay to Florida Bay. The distribution and growth of crocodiles are related to seasonal fluctuations in salinity. In addition, the survival of hatchlings has been linked

to periodic access to freshwater. How changes in freshwater inflow affect the distribution, abundance, and survivorship of hatchlings is unknown.

Clearly, changes in freshwater inflow into the Bay will influence the quality and quantity of habitat available to all life-history stages of manatees, turtles, dolphins, and crocodiles. The scientific basis for predicting the extent of the habitat change is currently weak. However, as coastal habitat outside the Bay diminishes in quality and quantity, the relative importance of the Bay to the protection and recovery of these species will likely increase. Therefore, investigation of the impacts of habitat change in the Bay upon all protected species groups is imperative.

Key Research Needs

Protected areas such as the Bay will likely become increasingly important as refuges for protected species as coastal development continues. To develop predictive models, information on the abundance and distribution of animals in the Bay is critical. These results will be used to evaluate the carrying capacity of the Bay for these species, an essential element of restoration management. Information on the movements and use of the Bay as nursery or developmental habitat is essential. Information needs to be collected over many years to delineate population trends in the species that have long generation times. Information on the impact of toxins and pollutants on protected species is critical if recovery is to be achieved.

For some species, such as osprey and bald eagle, available monitoring records are sufficient to determine the current status of populations in the Bay; for others, however, regular population monitoring should be initiated and continued. For all species, consistent censusing must be either continued or initiated to determine the impacts of habitat change on these populations. Monitoring of both the nesting and foraging components of all populations are needed. As such, all species can be used as indicators of ecosystem health. The accumulation of toxins has been documented for some species. The impact of this on individuals and on reproductive and hatchling success must be quantified.

Specific Tasks

For predatory birds:

i. Monitor the abundance and distribution of key species. The most commonly used method is via aerial survey counts. To evaluate hatching and fledging rates, nests must be routinely sampled.

ii. Determine the relative importance of specific areas for nesting, feeding and roosting within the Park and the Bay, using radio- and satellite-tracking tags.

iii. Analyze stomach contents to provide needed information on feeding and habitat preferences.

iv. Sample nests for egg and hatchling productivity.

v. Population changes can only be determined by monitoring these species in the Bay and adjacent coastal waters. On the larger scale, aerial surveys are an appropriate method to census animals and evaluate distributional changes.

For crocodiles:

vi. Nest censuses need to be used to determine population status.

For sea turtles:

vii. Netting studies are appropriate when accompanied by tagging as currently practiced. The use of point-transect sampling may also provide abundance estimates.

viii. Distribution and abundance data on legally protected species, Florida Bay habitat characterization and environmental parameter data need to be integrated in order to evaluate the effects of environmental changes on turtles.

ix. Radio-tagging studies should be undertaken to provide information on the movements of animals within and outside the Bay, including their migratory movements.

x. The examination of stranded animals should be used to provide additional information on habitat use and preference via stomach-contents analyses. Stomach contents should be examined via gastric lavage of living animals.

xi. Specific study of the fibropapilloma disease is needed to provide for mitigation and recovery.

For all species:

xii. Analyses of toxins in forage items and tissues must be completed and tissues from all life-history stages should be analyzed for contaminants.

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SUBREGION 9:

LOWER EAST COAST URBAN AREA

INTRODUCTION AND SCOPE

Subregion 9, the Lower East Coast Urban Area (referred to hereafter as the Lower East Coast), extends just over 100 miles from West Palm Beach to Florida City. It encompasses those portions of Dade, Broward, and south-central Palm Beach County that lie east of Everglades National Park and the Water Conservation Areas. The area is primarily urban, forming a megalopolis that stretches almost the entire extent of the Subregion, but it also contains substantial agricultural acreage, particularly in the southwestern part of Dade County. Both urban and agricultural areas receive benefits from what natural systems remain in the Subregion, including oxygen production, detoxification and dispersion of pollutants, nutrient recycling, fish and wildlife production, outdoor recreation, and tourism attractions (McPherson et al. 1976).

The Lower East Coast's demands for water, energy, recreation, housing, and other services have considerable impact on the other subregions of South Florida. The Lower East Coast is tied to these other subregions principally by water. Groundwater, dependent partly on recharge by the canals extending from Lake Okeechobee, is the major water source for the urban areas. Releases from the regional system help prevent saltwater intrusion along the coast. These demands affect the water needs of the lake and those areas connected to the lake by the St. Lucie Canal and the Caloosahatchee River. Water needs and drainage demands of the agricultural area in extreme western Dade County impact the water supply to Everglades National Park and Florida Bay. Dade County groundwater is the primary source of drinking water for the Florida Keys. Subregion 9 is on the downstream receiving end of many surface water discharges from other subregions. Florida Bay, Biscayne Bay, and the north Florida Keys receive discharges from the Lower East Coast. Residents of Subregion 9 and tourists benefit from the wildlife resources and recreational values of surrounding subregions, especially those near the metropolitan area, such as Biscayne National Park, Everglades National Park, Florida Bay and the Florida Keys, and the Water Conservation Areas. The recognized tourism values of these nearby areas enhance the image and economy of the Lower East Coast and are a primary reason many people travel to or through Subregion 9. In addition, the fishery resources of these areas and the products of the agricultural areas provide food for the Lower East Coast.

BACKGROUND

Description of the Natural Area

The Lower East Coast has many types of topographic features that provide varied habitats:

- coastal barrier islands with beaches and dunes - these are the southernmost barrier islands of the U.S. East Coast;
- an estuarine lagoon between the islands and the mainland;
- a narrow coastal plain occupied in part by shoreline mangroves;
- a linear ridge of higher land;
- interior short-hydroperiod wetlands, many of which have been drained;
- a few natural inland lakes, now much reduced in size;
- many artificial rockpit lakes and retention/detention ponds; and
- an extensive system of manmade freshwater canals, which has totally replaced natural tributary drainage.

The outstanding topographic feature region is the Atlantic Coastal Ridge, a narrow limestone ridge 2-10 miles wide that borders the Atlantic Ocean and forms a barrier between the ocean and the Everglades basin. The cities of the Lower East Coast initially developed along the ridge; now they extend far beyond it. North of Fort Lauderdale the bedrock is sandy limestone and is covered with a deep sand mantle of old dunes that forms ridges and elongated depressions. South of Fort Lauderdale the bedrock is Miami oolite covered with little or no sand, with the surface south of Coconut Grove essentially bare rock. This portion is often called the Miami Rock Ridge. There are numerous outcrops of the rock formation; one of most prominent natural exposures is Silver Bluff in Coconut Grove, bordering Biscayne Bay, where the ridge reaches its maximum height of 24 feet above sea level and maximum thickness of 34 feet. At its southern end, the ridge swings southwest, then west, and disappears in Everglades National Park, about 22 miles west of Homestead (Davis 1943; Harper 1927; Hoffmeister et al. 1967; Parker et al. 1955).

The ridge is breached in many places in Dade and Broward Counties by shallow sloughs, known as transverse glades. Historically, many of these transverse glades contained streams and rivers, which drained waters of the Everglades and fell in shallow rapids through the limestone ridge. The streams that occurred in Subregion 9 were, from north to south, Hillsboro River, Cypress Creek, New River, Snake Creek, Arch Creek, Little River, and Miami River. Frequently in the dry season, runoff disappeared into fissures in the limestone. In 1847, it was reported that running water could often be heard and seen 6-8 feet below the surface in the pine woods between the everglades and Biscayne Bay. In 1913 springs of considerable size were still seen along the rock ridges of the pineland. Fresh water also emerged in many springs along the shoreline of Biscayne Bay, even from the bay bottom. This natural system is now completely converted to an extensive system of drainage canals, which began in the New River basin in 1907 and in the Miami River in 1909. The largest of these are the West Palm Beach, Hillsboro, North New River, and Miami (Davis 1943; Harper 1927; Hoffmeister et al. 1967; Parker et al. 1955; U.S. Senate 1911). The hydrologic changes caused by canal drainage and lowered water table resulted in dramatic changes in plant communities, especially disappearance of marshes (e.g., around Clear Lake and Lake Osborne in Palm Beach County) and wet prairies (Austin 1976; Austin et al. 1977; Richardson 1977). Most of the wet prairies immediately west of the Coastal Ridge were destroyed between 1943 and 1970, including 80% of those in Broward and Palm Beach counties. Also destroyed were 6300 acres of pond-slough habitat in Broward County alone (Birnhak and Crowder 1974, as referenced in McPherson et al. 1976). The Cypress Creek Canal in Pompano Beach, Broward County, historically was a unique cypress slough forming one of the transverse glades (Moran 1979). Scattered remnants of cypress forest wetlands are still present in urban north Broward; some of these are preserved as parkland (Broward Co. Bd. Commissioners 1989b).

Another example of major hydrological alteration is in South Dade County. Under natural conditions, the lower C-111 basin received most of its runoff from the southern portion of the Coastal Ridge; these surface and groundwater flows comprised the primary source of freshwater inflow to northeastern Florida Bay. Now, with urban development of the Coastal Ridge and operation of the C-111, much of the natural runoff is diverted by canal to Biscayne Bay (USACOE 1994).

At the southern tip of the coastal ridge in Dade County, just inland of the mangrove band, is a broad, marl-forming, short-hydroperiod coastal prairie. It extends from Silver Bluff on the shores of Biscayne Bay south around the tip of the coastal ridge (Harper 1927). The characteristics of this area, including the marl (Gleason and Spackman 1974) and the freshwater wetland vegetation, probably resulted from groundwater seepage from the ridge.

The Coastal Ridge was historically covered with pines and palmetto, interspersed with hardwood hammocks. It was reported in 1906 that a band of timber 2-8 miles wide extended along the coast. At this time, many small towns existed along the Florida East Coast Railroad between Palm Beach and Miami, but there were no settlements at a distance of more than 2 miles west of the railroad, where the Everglades were described as presenting an unbroken front extending more than 60 miles (U.S. Senate 1911).

Even with intensive urban development, the Lower East Coast still contains many representatives of most natural plant communities characteristic of South Florida, although these are now reduced, fragmented, and stressed. These

include beach and dune; mangrove swamp; coastal saltwater marsh; freshwater marsh; maritime hammock; coastal strand; rockland hammock; pine rocklands; scrub; sandy pine flatwoods; and short-hydroperiod wet prairie. Some of these vegetation communities, as well as many individual plant species within them, are endemic only to South Florida and are protected in parks in the three counties.

Scrub habitat historically occurred along the Coastal Ridge in a narrow strip along the eastern shore of the mainland south to northern Dade County. It grew throughout a topographically complex series of parallel ridges and swales (Austin et al. 1977, 1987; Davis 1943; Harper 1927; Lovestrand 1990; Richardson 1977; Steinberg 1980). Swamps and marshes were common in depressions cut through the scrub ridges. The largest scrub ridge in Broward County was transversed on the north by the Hillsboro River system and on the south by the Cypress Creek system (Steinberg 1980). Remnants of this coastal scrub exist along the Coastal Ridge in portions of Subregion 9 north of Fort Lauderdale, in isolated sites surrounded by urban development. [Broward Parks and Recreation Div., undated(a); City of Boca Raton 1991; Davis 1943; Austin et al. 1987; Fernald 1989; Palm Beach Co. DERM, undated].

The subtropical pinelands on the Miami Rock Ridge are monospecific stands of South Florida slash pine with a diverse understory of palms, shrubby hardwoods, and herbs (Snyder 1986). Dade County probably has more endemic plant taxa (55-65) than any other Florida county, and most of these occur in the pine rocklands (Garvue 1994; Muller et al. 1989). In fact, the pine rocklands contain the third largest concentration of endemic native plants in the continental U.S. (DERM 1994b). Of 186 native species recorded during a pineland inventory, 67 were considered endemic to South Florida pinelands (Loope et al. 1979). Estimates of the extent of pineland that formerly existed on the ridge range from about 162,000-185,000 acres (Doren et al. 1993; Gleason 1984; Loope et al. 1979). Only 4400 acres of pineland remain in Dade County; just over half is in private ownership and not protected in parks. Many of the small remnants have been invaded by Brazilian pepper or are otherwise degraded (Doren et al. 1993; Loope et al. 1979). Only a few areas outside Everglades National Park are likely to be preserved (Snyder 1986). These include a few areas of considerable acreage managed by Dade County and some owned by the federal government.

The hammock, a dense forest with many species of tropical origin, has been considered the climax vegetation of South Florida (Alexander 1967; Alexander and Crook 1984; Davis 1943). Of the 128 species found in a rockland hammock southwest of Miami, 5% were endemic to South Florida, while 82% were also found in the West Indies. South Florida was the only location in the U.S. for 62% of the species (Phillips 1940). The Boynton Beach Hammock had 85% tropical composition (Austin and Weise 1972); the Pompano Beach Hammock had 87% (Alexander 1958). Historically, more than 500 hammocks (oak-palm or tropical hardwood) were scattered along the Coastal Ridge (Gleason 1984), northward into Brevard County (Richardson 1977). The largest hammock was the Brickell Hammock that bordered Biscayne Bay below Miami (Harper 1927). Hammocks occurred on the ridge wherever flowing water had carved caverns, sinks, or channels (Craighead 1984; Taylor 1991; Thorhaug et al. 1976). Hammocks exist now in only scattered remnants. Into the 1970s, the half-mile-long Boynton Beach Hammock was the last coastal hammock of its size north of the Keys (Austin and Weise 1972; Richardson 1977). Hammocks near the coast are now stressed by lowered water tables (Alexander and Crook 1984).

The most unique natural geological formation in Subregion 9 is on the northeast shore of Key Biscayne in Dade County. It is a reef composed of fossilized roots and pneumatophores of black mangrove, estimated at 1000-2000 years old, which may be the only one of its kind in the world (Hoffmeister and Multer 1965).

An estuarine system, through which the Intracoastal Waterway runs, separates the coastal barrier islands from the mainland. The two prominent estuaries in Subregion 9 are Lake Worth and Biscayne Bay. Lake Worth is being discussed in Subregion 3 (Loxahatchee River region). South Biscayne Bay, included in Biscayne National Park, is discussed in Subregion 8 (Florida Bay and Florida Keys). The significant estuaries considered in Subregion 9 are West Lake in Broward County and the north and central portions of Biscayne Bay.

West Lake is a 1400-acre coastal wetland and mangrove preserve with 262 acres of open lake that extends for 3 miles along the Intracoastal Waterway in Hollywood. Although surrounded by dense residential and industrial development, West Lake is the best example of mangrove community remaining in Broward County and the largest of its kind between West Palm Beach to Miami. It is also one of the largest mitigation projects ever conducted in Florida. The purchase agreement in 1985 included almost 200 acres of wetland creation. West Lake is an important nursery area for fish, especially snook ((Broward Co. Bd. Commissioners 1989b; Broward Co. Plan. Counc. 1989a; Broward Co. P&RD 1989; MacAdam 1990; G. MacAdam, pers. comm.). Another Broward mangrove preserve is located at Port Everglades at the mouth of the FP&L cooling canal (Broward Co. Bd. Commissioners 1989b).

Biscayne Bay is a subtropical lagoon about 40 miles long that extends the length of Dade County (Evoy and Schechtman 1986), making it a dominant feature of the county. The bay has been the subject of much study. Over 1,700 citations are listed in a recent bibliography on the marine environment of Biscayne Bay (Hale 1993). It is technically classified as a shallow, tidal bar-built estuary (Hela et al. 1957). North Biscayne Bay (north of Rickenbacker Causeway) is hydrographically complex because of massive dredge and fill activities and the presence of several causeways and many islands (most artificial) that alter circulation (Hela et al. 1957; Roessler and Beardsley 1975; Thorhaug et al. 1976; Wanless 1976). Since 1900, 49% of the submerged area of North Biscayne Bay has been permanently altered by dredging and filling and by construction of more than 90 miles of bulkheaded shoreline, artificial islands and causeways, channels, and cuts to the ocean (Alleman et al. 1994; Evoy and Schechtman 1986). Several relatively small tributaries enter the North and Central Bays. The flow of the Miami River is greater than the others entering North Bay combined but is insignificant compared to tidal flow through the bay (Hela et al. 1957; Michel 1976). The altered hydrological system has increased point-source discharge (Thorhaug et al. 1976); the canal system and the Miami River are the principal routes for pollutant runoff to the bay (Waite 1976). Until 1956 when a sewage treatment plant began operation, the Miami River was essentially an open sewer discharging untreated waste directly into Biscayne Bay (City of Miami 1992; Dade County DERM 1993b; Hela et al. 1957). Water quality of the Miami River is still adversely affected by sewage effluent and by agricultural and urban runoff (City of Miami 1992; Dade Co. DERM 1993b; Gulf Engineers 1993; Irwin, undated). Discharge from the Miami River is rapidly exchanged with coastal waters through Government Cut and Norris Cut inlets. (Lee and Rooth 1976). Arch Creek, a tributary to North Bay, has high levels of ammonia and coliform bacteria, significant amounts of metals in the sediments, and high levels of phthalates in its tributaries (Alleman et al. 1994). The most significant pollution problem in North Bay is leaching from the Munisport Landfill. This is a Superfund site placed on the National Priorities List in 1983 due to migration of leachate-contaminated groundwater from the landfill into a mangrove preserve (USEPA 1994b,c).

The shoreline of Biscayne Bay historically was lined by mangroves. Most of the shoreline vegetation has been altered by development and other anthropogenic impacts, including loss of freshwater flow, ditching and subsequent increase in salinity, clearing, dredge and fill projects, construction of seawalls, and erosion by boat wakes (Odum et al. 1982; Reark 1975; Teas 1977; Teas et al. 1976). Today substantial stands of mangroves exist at only a few sites, primarily in Oleta River State Recreation Area in the north Bay, on the west shore of Virginia Key, on the northwest edge of Key Biscayne, and on the mainland south of Coral Gables. It has been documented that alterations in hydrology (i.e., mosquito ditches and agricultural ditches) and the resulting increase in salinity has allowed mangroves to expand inland beyond the coastal band. This has resulted in a scrub mangrove community growing on former freshwater marl marshlands that were salinized as a consequence of drainage. These mangroves show overt signs of stress and probably suffer nutrient deficiencies (Ball 1980; City of Miami Plan. Dept. 1987; Reark 1975; Teas 1976).

The bottom of South Biscayne Bay is dominated by turtle grass (*Thalassia testudinum*), but in the portions of the bay most impacted by urban development turtle grass has generally disappeared. One extensive seagrass area that does remain in North Bay is north of the Julia Tuttle Causeway. This is probably the most biologically diverse and productive area in the bay and rivals any community sampled in South Bay. Much work has been done on techniques for replanting and restoring this seagrass in denuded areas, especially North Biscayne Bay (Evoy and Schechtman 1986; Thorhaug 1976; Thorhaug et al. 1976). The restoration of seagrass beds and mangrove

shorelines improves habitat for invertebrates in the bay (Voss 1976) and also provides habitat for fish. Studies in Biscayne Bay showed the most important determinant in abundance of juvenile fish was density of seagrass (Evoy and Schechtman 1986). Mangrove planting techniques have been developed, and since the early 1980s replanting of mangroves and seagrass has been required as mitigation for construction projects (Alleman, undated; Evoy and Schechtman 1986; Teas 1977).

At least 512 species of temperate and tropical fish have been recorded from Biscayne Bay (de Sylva 1976). Saltwater fish species, such as tarpon, are often found far upstream in the canal and river systems (Davis 1943; Kushlan and Lodge 1974). The bay supports commercial and recreational fisheries; pink shrimp, harvested in a baitfish fishery, is the most important species harvested by weight (Evoy and Schechtman 1986).

In 1974 the Florida Legislature established the Biscayne Bay Aquatic Preserve. It includes all publicly owned islands and all submerged lands from Sunny Isles Causeway (State Road 826) on the north to Card Sound Road (State Road 905A) in Monroe County on the south, excluding Biscayne National Park. It also includes the lower portions of most tributaries. Funds provided pursuant to this Act have been the main support for bay management programs (Evoy and Schechtman 1986). The 400 acres of shallow tidal flats and mangrove forests on the west side of Virginia Key have also been designated as a Critical Wildlife Area by the Florida Game and Fresh Water Fish Commission (FG&FWFC, undated).

Population

The Lower East Coast is the most heavily urbanized area of not only South Florida, but the entire state. With a combined population of more than 4 million people, the three counties of Subregion 9 are home to more than 30% of the residents of the state of Florida. Dade, Broward, and Palm Beach counties are 1, 2, and 3 respectively in the state's population rankings. Dade County itself comprises almost 15% of the state's population (Bureau of Economic and Business Research 1993).

Water Supply

Water availability in the region depends on rainfall and storage capacity in the surface and groundwater systems. The Lower East Coast is a producer, as well as South Florida's largest consumer, of fresh water. The state's heaviest rainfall occurs along the East Coast ridge between West Palm Beach and Miami (Davis 1943; McPherson et al. 1976), where the annual average is as high as 64 inches (1975 data). Rainfall decreases inland and is only 52 inches over Lake Okeechobee.

The Lower East Coast is dependent on shallow, unconfined aquifers for its potable water. Broward and Dade counties rely entirely on groundwater; groundwater accounts for 80% of Palm Beach County's potable water. Most of the groundwater (100% in Dade, 90% in Broward, 85% in Palm Beach) is pumped from depths of less than 150 feet; many wells are much shallower (Alvarez and Bacon 1988). The Biscayne Aquifer is the largest and most productive unit of the surficial system. It extends northward from Dade County, where its permeability is highest, into Broward and the southern and central parts of Palm Beach County. The aquifer is composed of sandy limestone and calcareous sandstone with many solution holes and cavities. The USGS considers it one of the most permeable aquifers ever investigated (Parker et al. 1955), and it is probably the most permeable water-table aquifer in the world (Kreitman and Wedderburn 1984). Aquifer recharge is mainly by direct infiltration from rainfall. This is supplemented by water carried into the area by canals to supply well fields and prevent coastal saltwater intrusion during the dry season (Plan. Dept. SFWMD 1992, 1993).

Drainage of interior wetlands has lowered the water table, altered the natural groundwater flow, eliminated coastal springs and artesian wells, and increased the amplitude of seasonal hydrological fluctuation along the Lower East Coast (Buchanan and Klein 1976; Fish and Stewart 1991; Parker 1984; Parker et al. 1955). In the early 1960s, small springs were still discharging through the bay bottom along shore about 10 miles south of Miami. The discharges were great enough to cause a salinity-based biological zonation (Kohout and Kolipinski 1967).

Saltwater intrusion has been a concern since coastal well fields showed evidence of increasing salinity more than 40 years ago. Because of the threat of saltwater intrusion, levels of fresh water near the saltwater interface must be maintained higher than the sea level (Plan. Dept. SFWMD 1992; Trimble 1986).

The Lower East Coast's natural drainage pattern of streams and transverse glades has been almost totally altered and replaced by a manmade system of canals. Roughly 3.2 million acre ft per year of freshwater empty to coastal estuaries in Subregion 9 through 28 main canals of the Central and Southern Florida Project. Half of these are in Dade County and discharge into Biscayne Bay (Cooper and Lane 1987a,b, 1988; Plan. Dept. Staff 1993). The discharges include stormwater, drainage water from agricultural and urban land, excess water from the water conservation areas, and water released to the Lower East Coast to recharge the groundwater and prevent saltwater intrusion. The volume, timing, and distribution of discharges are thought to differ substantially from that received by estuaries prior to development of the Project and precursor drainage works. Another system of canals, the South Dade Conveyance System, delivers a mandated supply of water to Everglades National Park and also supplies water to other South Dade canals to prevent saltwater intrusion (Cooper and Lane 1987b; Wedderburn et al. 1981).

Desalination to produce fresh water is a process that has been used in Florida since 1967, especially on the Southwest Coast and in the Keys, but it has not been used extensively on the Lower East Coast. In 1987, one Palm Beach County utility was using reverse osmosis technology to supply some potable water and a few other communities were investigating the technology (Khanal 1987). The source water for desalination can be seawater or brackish aquifer water, such as from the Floridan aquifer (Morin 1987).

Agriculture

The major land use west and south of the Coastal Ridge is agriculture (Parker et al. 1955). This is an important land use throughout the Subregion and provides large areas for aquifer recharge (SFRPC 1991). Agricultural lands are concentrated in the 150-square-mile South Dade Agricultural Area near Homestead; more than 90,000 acres were mapped as agricultural land in 1985 (Plan. Dept. SFWMD 1992, 1993), and over 80,000 acres were harvested in 1986-87 (Dade Co. DERM 1990a). Vegetables account for 56% of the total value of sales here. These include 18 kinds of traditional vegetables and 6 tropical vegetables, such as malanga and boniato. Winter tomatoes are the largest cash crop, followed by bush and pole beans, new potatoes, and yellow squash. Sweet corn and seed corn are also grown. Nurseries, including field, container, and greenhouse operations, account for 30% of agricultural value. Fruit crops contribute the remaining 14%. Many of the crops are not grown commercially anywhere else in the U.S. Dade County is one of the few places in the U.S. where tropical fruits (10 varieties) are grown, producing 90% or more of the U.S. supply of Persian limes and mangos (PBS&J 1992; Plan. Dept. SFWMD 1992, 1993). Farming here usually requires extensive site preparation. After bulldozing the vegetation, the surface rock is scarified, or rock-plowed, with heavy equipment to form a planting medium of rock fragments and pulverized limestone with a little soil. Native vegetation does not easily reestablish once the substrate has been altered in this way (Anderson 1986; Mierau 1975; Snyder 1986). In fact, such areas left fallow are prime sites for colonization by invasive non-native species that threaten nearby natural areas (Doren et al. 1990). Heavy fertilization and irrigation are needed for maximum yields; an estimated 80% of truck crops and fruit trees are irrigated. Heavy use of pesticides is also required [Anderson 1986; Dade Co. DERM undated(e), 1991; Mierau 1975; Snyder 1986].

Prior to construction of the Central & Southern Florida Project, farming practices in South Dade had been adapted to the natural variability of Everglades flooding and drying. Land preparation and planting would not begin until wet-season water levels had naturally receded. Agricultural practices began to change during the 1980s, partly because of a lower than normal decade of rainfall. Grove crops requiring year-round low groundwater levels expanded westward. Economic pressures forced row crop farmers to plant earlier in the season. Both changes led to additional demands to lower canal operational stages. Drainage and lowered water levels were a primary factor in the increased agricultural and residential development throughout low-lying areas of western Dade County, even west of the eastern protective levee, and also in other western portions of Subregion 9 (Anderson 1986; Centr. S. Fl. Flood Contr. Dist. 1974; McPherson et al. 1976; USACOE 1994).

Agricultural lands in eastern Palm Beach County include 14,000 acres of citrus and 15,000 of vegetables. Commercial horticulture is also important, and acreage of nurseries is predicted to double by 2010 (Plan. Dept. SFWMD 1993). In 1980, Palm Beach County designated a 26,000-acre tract between the Florida Turnpike and the Loxahatchee National Wildlife Refuge as an Agricultural Reserve Area. In addition to preserving agriculture, the designation limits development density and attempts to discourage county expenditures for urban services in the area (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a).

Broward County's land use plan also calls for preservation of agricultural and rural lands (Broward Co. Bd. Commissioners 1989a), but urbanization is expected to continue to reduce agricultural acreage. The Broward agricultural area covered 6,000 acres in 1989; down from 13,000 acres in 1950 (Broward Co. Bd. Commissioners 1989b). Although the land devoted to ornamental nurseries is expected to increase, acreage in vegetables and citrus may decrease to only double digits by 2010 (Plan. Dept. SFWMD 1993).

Invasive Nonindigenous Species

The Lower East Coast is the center of distribution of non-native plant and animal species introduced into the South Florida environment. Dade County near Coral Gables was one of the coastal sites where melaleuca was planted in the early 1900s, and melaleuca seeds were released by airplane over western Broward County in the 1930s (LaRoche and Ferriter 1992). In some cases, exotic plants have totally replaced native habitats; e.g., wet prairies replaced by melaleuca stands (Austin 1976; Richardson 1977). The 1993 list of Florida's most invasive plant species, published by the private, non-profit Exotic Pest Plant Council (EPPC) and agreed upon by consensus of a selected group of scientists, contains 126 species (EPPC 1993). Over 300 species of exotic plants are known to be naturalized in natural community fragments in Dade County south of the Miami River (Gann-Matzen 1994). The Dade County Park and Recreation Department is involved in intensive exotic removal and maintenance of its natural areas to prevent permanent damage to these areas from invasive non-native plants following Hurricane Andrew (Flynn 1994; Gann-Matzen 1994; Klein, undated; McHargue and Hammer 1994).

A draft U.S. Fish and Wildlife Service report identifies 82 nonindigenous fish species in Florida, many of which occur in South Florida (McCann et al. 1994). Cichlids, such as the oscar and the spotted tilapia, have been extremely successful in establishing populations throughout the Lower East Coast. Dade County is probably most affected; nearly all of its fresh and brackish waters, especially the canals, were infested by the early 1970s (Courtenay and Hensley 1979; Hogg 1976; Kushlan and Lodge 1974). Peacock bass were introduced to control other non-indigenous fish and as a game fish in southeast Florida canals, but it is slowly outcompeting native bass and bream (OTA 1993). Other fauna have also invaded the region, including the South American caiman in Dade County (Ellis 1980; McCann et al. 1994; Wilson and Porras 1983) and insects, snails, and other invertebrates that usually arrive through official ports of entry (Daigle 1984; McCann et al. 1994; OTA 1993; Roessler et al. 1977; Russo 1973). South Florida has more introduced and established reptiles and amphibians than any other area in the U.S.; many of these species were first observed in the urban areas of Dade County and were introduced as stowaways or as releases by animal dealers or pet owners (Wilson and Porras 1983).

Two exotic insects that have recently invaded the Lower East Coast are threatening native plants. A neotropical tortoise beetle from South America and the Antilles, was discovered in Davie, Broward County, in 1993 and has since been found in other locations including Bill Baggs Cape Florida State Recreation Area and Matheson Hammock in Dade County. This species feeds on native morning-glory leaves. Hurricane Andrew is suspected as the mode of introduction (Duquesnel 1994a). A weevil that feeds on native bromeliads apparently arrived in Fort Lauderdale around 1990 on bromeliads imported from Mexico. The wild pine and giant wild pine are favorite targets and have been upgraded from threatened to endangered status by the Endangered Plant Advisory Council. The weevil has been confirmed from Palm Beach International Airport south to central Broward County and in Castellow Hammock in Dade County (Duquesnel 1994b).

Protected Species

In Subregion 9, 24 animal species and 8 plant species might be found that are federally listed as threatened or endangered (J. Carroll, USFWS, pers. comm.; Coile 1993; Kale 1978; Layne 1978; McDiarmid 1978; USFWS 1980a, 1980b, 1990, 1993, 1994; Wood 1994).

County lists prepared by USFWS indicate 7 federally listed endangered or threatened plants occur in Palm Beach, Broward, and Dade counties (USFWS 1994). These are: 5 pine rockland species (Small's milkpea, deltoid (wedge) spurge, crenulate lead-plant, Garber's spurge, and tiny polygala); four-petal (scrub) pawpaw; and beach jacquemontia. Four of the listed species are found only in Dade County pine rocklands. The tiny polygala, extant in Dade County, has been extirpated from Broward County (Coile 1993). The rockland plants are considered rare because of habitat loss. 12 other pine rockland species are candidates for listing and the state lists 32 pine rockland plants as endangered or threatened (DERM 1993a, 1994b). The Florida Department of Agriculture and Consumer Services (FDACS), Division of Plant Industry, regulates harvest of plants in the state and lists plants as endangered, threatened, or commercially exploited. The lists are statutorily designated via the Preservation of Native Flora of Florida Act (FDACS undated; State of Florida, undated; Wood 1994). A total of 65 plant species on the state endangered plant list (including those on the federal list) occur in one or more of the three counties of Subregion 9. Carter's mustard is a federally endangered species that, although not on the USFWS county list, is reported by the state to occur in Broward County; it has been extirpated from Dade County (Coile 1993). The Florida royal palm is a C1 candidate for federal listing for which there is substantial information on vulnerability (USFWS 1994).

The federally listed endangered or threatened animals that reside in or move through Subregion 9 are:

Reptiles:	Loggerhead, green, hawksbill, leatherback, and Kemp's ridley sea turtles; American alligator; American crocodile; Eastern indigo snake; Atlantic saltmarsh snake.
Birds:	Florida scrub jay; bald eagle; wood stork; Everglade snail kite; Arctic peregrine falcon; piping plover; roseate tern; Cape Sable seaside sparrow; red-cockaded woodpecker; Audubon's crested caracara; Kirtland's warbler; and Bachman's warbler.
Mammals:	West Indian manatee, Florida panther.
Invertebrate:	Stock Island tree snail.

Sea turtles (primarily loggerheads, greens, and leatherbacks) nest all along the coast of the subregion, especially in Broward and Palm Beach counties, with the entire southeast coast of Florida supporting more than 97% of the state's nesting. This coast is one of the four major loggerhead rookeries in the world. Turtles, however, have to deal with many human conflicts resulting from beach development, including nighttime beach lighting and pedestrian traffic (Broadwell 1992; Burney and Mattison, undated; Burney et al. 1990, 1994; Burney and Margolis 1993; Conley and Hoffman 1987; Fletemeyer undated, 1977, 1983, 1984, 1990, 1991; Harris et al. 1984; Mann 1977; Margolis 1993; Mattison et al. 1990; NMFS and USFWS 1991a, 1991b, 1992, 1994; Reiners et al. 1994; Salmon et al. 1994; Teas, W., pers. comm.; Town of Palm Beach 1993; Wershoven, J.L., and R.W. Wershoven 1992; Wershoven, R.W., and J.L. Wershoven 1989, 1992; Witherington 1990; Witzell, W., pers. comm.; Wolf 1989). Juvenile green turtles have frequently been observed by divers along nearshore hardbottom areas of Palm Beach County In addition to beach development, threats to turtles include recreational diving on the reefs, boating activities, and frequent freshwater discharges from water management canals during heavy rainfall. The discharges may be linked to algae blooms that out-compete preferred algal forage (Wershoven, R.W., and J.L. Wershoven 1992).

The alligator is a common resident of Lower East Coast wetlands, even in urban areas. This often results in conflicts in residential subdivisions built along lakes or canals and on golf courses with lakes. The alligator is now listed as threatened because of similarity of appearance to the crocodile. The crocodile historically occurred as far north as Lake Worth; nesting occurred in Biscayne Bay as far north as Miami Beach. Crocodiles apparently inhabited most creeks and rivers flowing from the mainland into Biscayne Bay, in creeks and swamps north to Hallandale, and on Virginia Key. As late as 1967, a 6-foot crocodile was shot on Miami Beach. The crocodile's

favored natural habit -- saltwater marshes with sandy, undisturbed high spots -- has been almost completely destroyed. During surveys in 1977-80, crocodiles were found residing in power plant canals in Fort Lauderdale in Broward County. In 1978, one was shot in Fort Lauderdale. The crocodile's range in Subregion 9 is now restricted to extreme southeast Dade County at Turkey Point Power Plant, where nesting has been documented since 1978. This site is one of three major crocodile nesting areas in South Florida; the other two are Everglades National Park and Crocodile Lake National Wildlife Refuge on north Key Largo. The power plant site is ideal habitat with 168 miles of cooling canals, abundant food, and secure nesting sites on spoil berms along the canals. It contributes about 10% of the hatchlings to the South Florida population. Crocodiles have also nested along Highway 1 between the mainland and Key Largo; being struck by automobiles along this stretch of road is a common cause of crocodile deaths. (Gaby et al. 1985; Garlock 1994; Kushlan 1988; Kushlan and Mazzotti 1989; Ogden 1978).

Although it is protected, collection of the indigo snake constitutes the most profitable illegal trade in Florida (Enge 1991). The indigo snake adapts moderately well to disturbed areas, and southeast Dade County supported the largest population of this species in South Florida. Urban development was planned for the land east of Homestead in the early 1980s, and it was expected that the indigo snake would disappear from southeast Florida if this area was not maintained for agriculture (Wilson and Porras 1983). The Atlantic saltmarsh snake occurs only in Palm Beach County.

The decline of the scrub jay throughout its range is attributed almost entirely to loss of scrub vegetation habitat to agriculture, silviculture, and commercial and residential development. It is listed only from Palm Beach County and might be found in scattered patches of scrub along coastal sand ridges (Fernald and Toland 1991; Fitzpatrick et al. 1991). A nesting pair was reported on the Yamato Scrub tract in southeastern Palm Beach County. (Fernald 1989). The wood stork, bald eagle, and snail kite would most likely be seen in the remote western portions of the Subregion 9, adjoining the Water Conservation Areas and Everglades National Park. The wood stork also found in the extreme southern and southeast wetlands of Dade County (Alleman et al. 1994). A pair of bald eagles unsuccessfully tried to nest during the early 1980s in the Virginia Key area of urban Dade County (Evoy and Schechtman 1986). The caracara and red-cockaded woodpecker are listed only for Palm Beach County. The Cape Sable seaside sparrow might be found just east of Everglades National Park in Dade and Broward counties.

The peregrine falcon is a migrant through the area, often following the barrier beaches, and is also a winter resident (Kale 1978). Bill Baggs Cape Florida State Recreation Area on Key Biscayne is a significant migration point for peregrines (Evoy and Schechtman 1986), and they are known to overwinter in the metropolitan Miami area (C. Goodyear, pers. comm.). The two listed warblers are extremely rare and would only be encountered during migration.

The manatee is a coastal resident throughout the subregion, seriously endangered by interactions with man, such as collisions with boat propellers and drowning in flood gates and drainage culverts. During severe cold weather, manatees regularly seek refuge in warmwater outfalls at the Port Everglades Power Plant and the Dania cutoff canal in Broward County. Dade County presently has no artificial warmwater refuges that operate regularly and are used by manatees (DERM 1994a; USFWS 1980b).

Populations of the Stock Island tree snail (federally endangered) and Florida tree snail (state species of special concern, see below) occurred at Monkey Jungle south of Miami, where they had been transplanted. Only a few days after Hurricane Andrew devastated the hammock habitat at Monkey Jungle on 8/24/92, an effort was initiated by USFWS and the University of Florida to rescue the snails, including many varieties and forms that are now extinct in the Keys, that were exposed to direct sunlight because of canopy loss and house them until the hammock could recover (Emmel 1992).

The southeastern beach mouse, a federally threatened species, was know to occur in Subregion 9 south to Hollywood Beach in Broward County. Intense development eliminated all suitable habitat (relatively undisturbed beach dunes with extensive sea oat zones seaward of intact secondary dunes) in Broward, and the beach mouse has

most likely not survived in either Broward or Palm Beach counties. One or two sites in Palm Beach County might be able to support populations if the beach dune habitat is restored and maintained (Humphrey et al. 1987; Robson 1989a).

In addition to the federal list, several additional species of animals that may occur in Subregion 9 are listed as endangered or threatened by the state of Florida (Wood 1994) or are candidates for federal listing (USFWS 1994). The Florida mastiff bat, listed as endangered because of habitat loss and human persecution, is a C1 candidate for federal listing. It primarily occurs along the coastal ridge in urbanized Dade County. It has been recorded from Broward County, but most recent records are from the Miami/Coral Gables area (Robson 1989b; Robson et al. 1989). The white-crowned pigeon, reported to spend summers in Coastal Ridge pinelands (Alleman et al. 1994), is considered threatened by the state, as is the least tern, which is impacted by human interference in its beach nesting areas (Wood 1994). The least tern formerly nested intensively along the causeways and dredge fills in Biscayne Bay (Evoy and Schechtman 1986; Owre 1976). A 1974 survey documented least tern nesting on rooftops of shopping malls, supermarkets, and office buildings in several locations in Subregion 9 (Fisk 1975). The Miami blackheaded (rimrock crowned) snake is another state-threatened species.

The state of Florida also classifies certain animal species as "species of special concern," many of which are C2 candidates for federal listing and do not have enough information for federal listing. Many of these occur in Subregion 9 and include the Florida tree snail; gopher tortoise; burrowing owl; brown pelican; prairie warbler; Sherman's fox squirrel, Florida mouse, Florida gopher frog, several wading birds (e.g., roseate spoonbill, little blue heron, snowy egret, American oystercatcher, and tricolored heron), and two fish species (common snook and mangrove rivulus) (USFWS 1980a,b; Wood 1994). The gopher tortoise occurs in isolated populations south to north Dade County. It is an important component of the ecosystem because of the ecological importance of its burrows; 360 species of animals, including other protected species (e.g., indigo snake), use these burrows and some cannot exist without them (Cox et al. 1987; Puckett and Franz 1991). A 14-acre tract of scrub at the Fort Lauderdale Executive Airport is managed as a gopher tortoise preserve (Broward Co. Bd. Commissioners 1993b). The burrowing owl exists only in scattered populations in the developed parts of coastal areas (Millsap, undated). Areas of sandy scrub, such as in southwest Broward County, were ideal habitat prior to development. The owl has tried to adapt to habitat alteration by nesting in locations such as airport runways, golf course sand traps, and children's sandboxes (Consiglio and Reynolds 1987).

Rookeries important to many of the protected wading birds are among the most conspicuous natural features of the coastal area. Large Dade County rookeries exist at Greynolds Park in North Miami; on Bird Key and other spoil islands in North Biscayne Bay; and on Virginia Key, Key Biscayne, and Chicken Key in Central Biscayne Bay. In Palm Beach County, a rookery is located on Fisherman's Island in Lake Worth. In Broward County, they have been identified on islands in lakes at Fort Lauderdale Executive airport and a power plant (Alleman et al. 1994; Kushlan and White 1977; Metro-Dade Plan. Dept. 1988a; Nesbitt et al. 1982; Osborn and Custer 1978).

The Florida tree snail is found only in the southern part of the Lower East Coast. It was historically widely distributed in the tropical hardwood hammocks that lined the East Coast Ridge as far north as Boynton Beach in Palm Beach County, with snails in each individual hammock exhibiting a different color form. As intense development began leveling most of the hammocks even before 1900 (including those in Boca Raton and Fort Lauderdale, the Yamato Hammock in Boynton Beach, and the vast Brickell Hammock in Dade County), the populations of tree snails were greatly reduced. Populations survive primarily in remnants of hammocks preserved as parks. (Bayer 1948; Clench 1946; Craig 1973; Montgomery 1975; Simpson 1929; Voss 1976).

MAJOR ISSUES

Appendix A summarizes many of the research, monitoring, restoration, and evaluation projects that have been conducted or initiated in the Lower East Coast to address the issues identified in this section. Generally, the

projects listed in the appendix are limited to those conducted over the past 20 years. Earlier surveys and projects are discussed in the above background section.

Human Population Growth

Between 1970 and 1990, the population of the three counties of Subregion 9 increased by 81% overall. Although Dade County has the highest population, the other two counties exhibited the highest growth rates. Over just the past two decades, Dade County had a population increase of 53%, while the population of Broward County grew by 102% and that of Palm Beach County grew by 147%. The major increase in Broward's population occurred during the 1970s (64% increase during 1970-1980, 23% during 1980-90). Palm Beach County had a similar increase during the 1970s (65%) and continued explosive growth during the 1980s with another 50% increase. Projections show that the populations of Dade and Broward counties are expected to grow about 30-40% between 1990 and 2010. For the same period, the population of Palm Beach County is projected to increase by 85% to 1.6 million (Bur. Econ. Bus. Res. 1993; Plan. Dept. SFWMD 1993). The population of Pompano Beach in Broward County increased almost 700% between 1950 and 1970 and changed from an agricultural community to a residential city with a shoreline dominated by highrise condominiums (Moran 1979). This rapidly expanding population, with its attendant demands and needs for land and services, has changed the entire natural South Florida ecosystem and contributes to most of the problems addressed in this section (Bur. Econ. Bus. Res. 1993; Joint Cent. Environ. Urban Problems 1985a; Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a; South Florida Regional Planning Council, undated).

Land Development

Intense development has been occurring along the Lower East Coast for most of this century. In 1927, a naturalist reported that "developers" (his quotation marks) in South Florida were "trying to destroy the vegetation as fast as possible, to make room for cities and farms" and areas of vegetation he had studied in prior years were gone forever. He was concerned that "developers" were working faster than the botanists and destroying plants before they could be studied. He specifically mentioned that much of the Brickell Hammock near Miami was being turned into valuable building sites (Harper 1927).

The westward expansion of development in Subregion 9 continues to convert wetlands and agricultural fields to housing subdivisions, shopping centers, roads, office complexes, and, potentially, commercial theme parks. Both urban and agricultural developments are expanding westward into the buffer wetlands just east of the Water Conservation Areas and Everglades National Park. Some of the most rapid development, or proposed development, is now occurring in southwest Broward County (SFRPC 1989, 1990), much of which is flood-prone wetlands (Broward Co. Bd. Commissioners 1989b; Broward Co. Plan. Counc. 1989b, 1991). It has been emphasized that great caution must be exercised in development of this area because of its low topography, lack of slope, poorly drained soils, and potential for long periods of standing water (Broward Co. Bd. Commissioners 1989b; Burns et al. 1982). Many years ago, the sensitivity of this area was realized. In 1976 voters supported a moratorium on growth in the area, and in 1981 the Broward planning agency determined this area should be declared an area of local critical concern and development should be discouraged. It has been reported that 45% of Broward's new-home demand is for houses in southwest Broward (Sheridan 1994). In February 1994, a Miramar developer's proposal to build almost 4,000 homes near U.S. 27 in this area was just narrowly defeated by the Broward County Commission (Tanfani 1994). In comments on this proposal to the Broward County Board of Commissioners, the Superintendent of Everglades National Park requested that it be deferred, if not denied, until completion of South Florida restoration and water supply planning efforts. He stated that further development in remaining wetlands would make it difficult for Broward County to assure long-term water supplies and flood control and would severely constrain options for restoration of the Everglades (Ring 1994).

Also, the Blockbuster theme park is rapidly moving through the approval process at both the local and state level for development on wetlands in north Dade County and southwest Broward County. The Broward County Master Plan identifies these lands as "flood prone" and "wetland." The Dade County wetland area was owned by the state

and has been turned over to the County to facilitate this development. Little thought was given to how this development would affect the water table and the ability to manage water to support the South Florida Ecosystem Restoration effort while maintaining the other functions of the Central and Southern Florida Project. The developers claim the theme park will enhance water supplies (Zaneski 1994a), but it is possible development in that area could have a detrimental effect on both water quantity and water quality.

Land development impacts water supply because it reduces areas of standing water and often leads to a lowering of the water table, which means that less water is stored in the aquifer. Because of the highly permeable surficial aquifer in south Florida, a lowering of the water table in one area affects the water table for miles around. Stormwater discharge increases after land is developed, not only because of additional drainage works to provide flood control, but also due to creation of impervious surfaces such as parking lots, roads, foundations, and patios. This loss of open space results in reduced infiltration into soils and groundwater and reduced aquifer recharge potential (Browder 1991; Browder et al., undated; Centr. S. Fl. Flood Contr. Dist. 1973; Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a; Moran 1979). A recent Miami Herald article publicized these problems and emphasized that water management experts have difficulty predicting the results of disaster-level flooding from heavy rainfall because so much of Dade and Broward counties has been paved in the last 20 years (Russell 1994). It is not known what would happen during situations such as August-September 1981, when Homestead recorded 49 inches of rain from Tropical Storm Dennis and other subsequent storms and a large portion of South Dade was flooded for more than 2 months (SFWMD 1982b); or January 21, 1957, when the area west of West Palm Beach received 21.5 inches of rain (USACOE 1992).

Increased density of development and urbanization in the western portions of Subregion 9 and its effect on flooding risk have been major concerns of the South Florida Water Management District (SFWMD) for many years, especially how to continue providing drainage improvement without encouraging intensification of development (Burns et al. 1982; Centr. S. Fl. Flood Contr. Dist. 1973, 1974; Joint Cent. for Environ. & Urban Problems 1985a; Khanal 1975, 1982; SFWMD 1984b, 1987; Whalen and Cullum 1988). A major canal system redesign effort is underway in Palm Beach County, necessitated by flooding in western portions of the county now urbanized. Development in this area has already surpassed the basin's land use projection for the year 2025 as estimated in 1972 (USACOE 1992). It was reported that a development corporation observed a drop in the water table of 6-8 ft over a 5-year period prior to 1976 in one area of Palm Beach County being urbanized (Richardson 1977). The area around the Cypress Creek Canal in Pompano Beach, historically a cypress slough, became a flood hazard after urbanization (Moran 1979).

A good example of how residential and agricultural development can encroach into unprotected wetlands and affect water management can be found in South Dade County. Canal stage regulation schedules influenced by isolated agricultural and residential communities established in the wetlands of extreme southern Dade County led to further lowering of the water table in South Dade County. This has decreased the hydroperiod in wetlands of Everglades National Park and freshwater flow to Florida Bay.

Land development also affects water quality through chemical contamination and saltwater intrusion. Contributing to contaminant loads, principally by stormwater runoff, are lawn fertilizers, pesticides, and pet wastes from residential areas; metals and solvents from industry; fuel, grease, and oils from highways, parking lots, and airports; and leachates from landfills (Alleman et al. 1994; Broward Co. Bd. Commissioners 1993b; Holler 1989; Howie and Waller 1986; Mattraw and Miller 1981; Mattraw et al. 1978; Miller and Mattraw 1982; Moran 1979; Waite and Greenfield 1977; Weinberg et al. 1980; Whalen and Cullum 1988). Delray Beach and Riviera Beach in Palm Beach County are examples of cities that have had to close wells because of contamination or saltwater intrusion. Broward County has also been forced to shut down many coastal wells because of saltwater intrusion (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a). Pesticide use on golf courses is a particular concern (see section below on groundwater and surface water quality).

County planning documents emphasize that land development and population growth must be managed in an ecologically compatible manner consistent with environmental protection (Broward Co. Bd. Commissioners 1989a,b,

1993a,b; Metro-Dade Plan. Dept. 1988a,b, 1989, 1993). It often appears, however, that most land development occurs without adequate consideration of its impacts on the ecosystem, including water use, hydrologic changes, and elimination of wildlife habitat. It is usually not recognized that controlling development is necessary to preserve the economic base as well as the natural environment. Upland and wetland areas are important as wellfield sites, and uplands serve as recharge areas. Wetlands provide storm protection and floodwater retention and function as water purifiers. Beaches provide recreational opportunities and support tourism; dunes provide storm protection. Coastal mangroves contribute directly to maintenance of fisheries (Gleason 1984; SFRPC 1991). In many cases, development costs are increased by destroying the self-managing capabilities of the natural communities (Browder et al., undated).

Recent GIS analyses illustrated the pronounced urban encroachment on the western edge of the Lower East Coast urban area; in many locations encroachment on natural areas is more intense than would be expected from population growth and housing construction data (Walker and Solecki 1994). As westward development proceeds, the South Florida Regional Planning Council has emphasized the necessity of looking at the balance between development, available infrastructure and water supply, natural resources, and the quality of life (Centr. S. Fl. Flood Contr. Dist. 1974; SFRPC 1989). Palm Beach County attempted to limit westward growth in 1980 when it designated a 26,000-acre area west of the Turnpike as an Agricultural Reserve Area. One objective of this was to discourage county expenditures for extension of services such as water and sewer lines, schools, and fire protection beyond the designated Urban Service Area (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a). The Broward County comprehensive plan provides exceptions from level of service standards to encourage building in urban areas already developed and to discourage urban sprawl and reduce development pressures on rural and agricultural areas. (Broward Co. Bd. Commissioners 1993a).

Planners involved in post-hurricane reconstruction of South Dade County are attempting to address the cumulative impacts of development and consider natural resource and water quality values during redevelopment of the area. Ideas that arose in an area-wide planning workshop in late 1992 emphasized reclamation and protection of wetlands and other natural areas, protection of water quality and quantity, and rebuilding in existing urban areas instead of in peripheral undeveloped areas (Univ. of Miami and Florida Internat. Univ. 1992).

Water Conservation for Wildlife and Human Populations

Demand for water by the Lower East Coast is out-of-phase with the natural seasonal hydrologic cycle; it is highest during the dry season (November through May) when only 35% of the rainfall occurs (Browder et al., undated; Lin et al. 1984; Plan. Dept. SFWMD 1992, 1993; Storch 1975). Demand is expected to increase enormously. Projected demand on the public water supply for the year 2010 is estimated to increase over 1990 demand by 43% in Dade County, 68% in Broward County, and 115% in Palm Beach County (Plan. Dept. SFWMD 1993). Excessive withdrawals from the surficial aquifer can cause environmental problems such as shortening of the hydroperiod in nearby wetlands. The waste of treated effluent is a major issue. Roughly 588 million gallons of water per day (MGD) (214 billion gallons per year, or 0.66 billion acre ft per year) are lost to the system as treated wastewater effluent; 60% is discharged to the ocean, 40% is injected into deep wells (1991 data, SFWMD). At least 400 MGD (68% of the total) are suitable for recovery for irrigation.

Florida statutes require water reuse feasibility studies. The Administrative Code requires that water management districts designate critical water supply problem areas and make reuse mandatory within those areas, unless reuse is not economically, environmentally, or technically feasible, and requires reuse feasibility studies for new or expanding wastewater facilities discharging to surface waters (Adams et al. 1984; PBS&J 1992). Reuse is the application of reclaimed water for beneficial purposes, such as landscape or agricultural irrigation, groundwater recharge, industrial uses, or environmental enhancement (wetlands restoration) (Plan. Dept. SFWMD 1992). Reuse of wastewater could help mitigate present or future inadequacies in the regional water supply during a drought. Reuse could substitute for other changes to the system as a method to improve water supply. This approach is most applicable when reuse involves water that would have been disposed of by deepwell injection or ocean outfall. If it substitutes for percolation, benefits to the regional supply would be greatly reduced (Adams et al. 1984).

In an evaluation of its region done by the SFWMD, the Lower East Coast counties of Palm Beach, Broward, and Dade represented 73% of the potential capacity for wastewater reuse. Palm Beach County alone represented 34% (Adams et al. 1984). Some reuse systems have been implemented in municipalities and developments in Subregion 9. The majority of these used treated effluent to irrigate golf courses; several were used for other landscape irrigation. The use of wastewater was primarily an economic decision because it was a low-cost disposal method. Some of these systems were discontinued in favor of deep-well injection disposal when surface water discharge regulations became more stringent. For example, requirements for backup systems increased the costs of water reuse and treating wastewater for reuse often became more costly than procuring water from alternative supplies (Joint Cent. Environ. Urban Problems 1985b,c,d). A feasibility study done in Palm Beach County by the SFWMD found that few existing treatment plants or irrigation users would voluntarily participate in a wastewater reuse system because it would not be economically advantageous (Adams et al. 1984). In 1992, the city of Boca Raton was initiating an extensive dual reclaimed water system that would reduce potable water consumption and saltwater intrusion (Plan. Dept. SFWMD 1992).

A major use of water in Subregion 9 is for landscape irrigation, especially during the dry season. In the three counties, average annual irrigation demand by golf courses is expected to be more than 37 billion gallons per year by 2010, with 23 BGY in Palm Beach County alone (Plan. Dept. SFWMD 1993). Xeriscaping is being intensively promoted as a water conservation technique in urban areas, especially by the SFWMD [Plan. Dept. SFWMD 1992; SFWMD undated(b),(c)]. The District recently won an award from the Florida Native Plant Society for xeric landscaping used around its new building in West Palm Beach (FNPS 1994). The Tropical Audubon Society has used xeriscape principles to restore the grounds of its headquarters in South Miami, Dade County, as a demonstration project (Link and Lippincott, undated). In addition, the Florida Department of Transportation is planning to initiate a policy that all wildflowers used in landscaping of state highways must be native species (L. Burnett, FDOT, pers. comm.). The FDOT is also experimenting with plantings of saw palmetto, which does not need irrigation or pesticides (C. Higgins, FDOT, pers. comm.; Kollin 1994). The Dade County master plan calls for xeriscape and native landscaping wherever feasible, especially in salt-intruded areas where public water is used to water lawns, golf courses, and other landscaped areas (Metro-Dade Plan. Dept. 1993).

Water supply backpumping represents a structural approach to water conservation in which excess stormwater runoff is pumped westward back into regional storage areas (Plan. Dept. SFWMD 1992; SFWMD 1982a). The primary problems associated with backpumping are the expense of building and operating large-capacity pumping facilities and the potential adverse environmental impacts of periodically storing large volumes of runoff of unacceptable quality that might cause nutrient loading or pesticide contamination. Backpumping potential has been evaluated in most SFWMD basins (Plan. Dept. SFWMD 1992; SFWMD 1984b; USACOE 1992).

Davis (1943), in discussing the need for water reservoir areas five decades ago, emphasized that water conditions in the Everglades must be considered in maintaining water supplies for the coastal cities. Recently, several projects have been proposed for water storage areas to recover stormwater being drained to the ocean from Subregion 9. Storage areas are proposed for the western edge of the subregion, adjacent to the east boundaries of the present Water Conservation Areas and Everglades National Park. These include stair-stepped marshes (National Audubon Society 1994) and lake preserves at former rock mining sites (Larsen and Associates 1992).

A policy statement on growth management in Palm Beach County listed water needs of native ecosystems as an issue needing consideration (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988b). A major project related to water conservation for wildlife is investigating the effects of increased water deliveries to Taylor Slough in Everglades National Park (USACOE 1993). A negative human impact of these deliveries may be increased flooding potential in agricultural and residential areas in Subregion 9 just east of the Park, due to higher canal stages and groundwater elevations. The SFWMD considers increased water demands and associated drawdowns of the groundwater a threat to short-hydroperiod wetlands in the western portions of Subregion 9 (Plan. Dept. SFWMD 1992, 1993).

Quantity and Quality of Freshwater Flow to Estuaries

Estuaries, particularly Biscayne Bay, are being detrimentally affected by the impact of sporadic, short-term, extraordinarily high-volume canal discharges (Alleman et al. 1994). The occasional releases from the C-111 canal into Manatee Bay, which opens into Barnes Sound in the southern part of the Biscayne Bay system, are an extreme example (Browder 1991). Lake Worth is also subject to extremes of freshwater discharge (USACOE 1992). Other receiving areas for canal discharges are detrimentally impacted repeatedly, though not so severely, each year. The estuaries are also stressed by long periods with little or no freshwater inflow. Lack of flow during dry periods is caused by draining rainwater to the coast as soon as it falls. The naturally occurring slow seepage of groundwater into estuaries from the coastal ridge during the dry season has been eliminated by the lowering of the water table.

Most surface runoff of nutrients and contaminants from agriculture and urban land uses is discharged to the estuaries. These contaminant loads are not being adequately regulated to prevent damage to coastal ecosystems. Existing laws, standards, regulations, and enforcement may all be insufficient. The SFWMD considers stormwater runoff to be the source of most water quality problems in Biscayne Bay (Alleman et al. 1994). A system that rates intensity of "hazard normalized application" of pesticides by calculating pounds applied/acre of drainage area/year ranked Biscayne Bay the second worst estuary in the U.S. for per-unit-area application of the more hazardous pesticides. Applications of the insecticides endosulfan (37,000 lbs in the Biscayne Bay watershed) and chlorpyrifos (6,000 lbs) were most responsible for the rating. Endosulfan is commonly applied to tomatoes and is ranked as the most hazardous pesticide found in the marine environment because of its acute toxicity, ability to concentrate in fish tissue, and long time period to break down in the environment (Humphreys 1993; Pait et al. 1992). Much of the agricultural watershed of South Dade County also drains into Florida Bay. A recent preliminary pesticide survey found quantifiable levels of endosulfan in most of the stations sampled in the C-111 canal system and at one station in Florida Bay. The highest levels were found in the C-111 near the entrance to Everglades National Park. Contaminant concentration of agricultural nonpoint source runoff must be considered in management plans to increase freshwater flow to the Everglades (Scott et al. 1994).

Quality of Groundwater and Inland Surface Water

Because of the shallow depth of the aquifer, groundwater contamination is a constant threat. Numerous contamination sites have been identified in Dade, Broward, and Palm Beach counties; some of these are close to active public water supply wellfields. Cleanup of these sites or other protective measures may be necessary before additional wellfields can be developed (Plan. Dept. SFWMD 1993). Dade County alone has over 4700 hazardous materials sites, 175 industrial waste sites, and 140 agricultural waste disposal sites (Plan. Dept. SFWMD 1993). There is the possibility of groundwater contamination in agricultural areas from the use of chemicals (pesticides, herbicides, fertilizers) if best management practices are not used, especially in those areas near wellfields [Anderson 1986; Dade DERM undated(e), 1990a, 1990b, 1991, 1992; SFRPC 1991], and also in urban areas from stormwater runoff (e.g., from highways, Howie and Waller 1986). Evaluation of risks to groundwater from agrichemical use is difficult because of inadequate data on local usage and the lack of a central repository of such data. Several regulations require recordkeeping, etc., but do not require consistent reporting to regulatory agencies or require reporting only when threshold amounts are exceeded (Dade Co. DERM 1991).

Trihalomethane formation, caused by an interaction of dissolved organic carbons in raw water supplies with the chlorine used in water treatment, is a problem in some southeast Florida water treatment plants (Symons et al. 1975). Trihalomethanes have been associated with human cancer and genetic defects. Dade County recently installed air strippers, spending $30-$40 million in funds provided by EPA, to solve the problem. Although effective in removing both trihalomethanes and industrial pollutants found in some wellfield waters, the filters have to be replaced periodically and are costly (J. Baker, DERM, pers. comm.). Furthermore, the air pollution implications of the air filters have not yet been addressed, and scrubbers may be needed (J. Baker, pers. comm.). Officials of Sunrise in Broward County have also had to reduce trihalomethane levels in the water supplied to several municipalities (Miami Herald 1994). The Biscayne Aquifer is recharged not only by rainfall but also by canal flow from Lake Okeechobee and the Everglades. Without disturbance, Everglades waters are naturally clear

(Gleason and Spackman 1974). The main source of the trihalomethane problem may be drainage of organic soils, which is causing subsidence and release of dissolved organic carbons (Reddy 1982). Over the last 2 years, levels of lead that exceed federal standards have been found in nine Broward County communities and seven Dade County communities (Miami Herald 1994).

Contaminants are also found in the inland canal systems (see above). The use of pesticides on Florida golf courses in or near wetlands or adjacent to water bodies or wellfields is a particular concern. The pesticide often used to control nematodes in turf is Nemacur. The active ingredient in Nemacur is fenamiphos, which is highly toxic to wildlife. Half of all wildlife kills investigated by the FDACS in the state since 1991 involved Nemacur. A Miami Herald article reported recent wildlife kills following applications of Nemacur to area golf courses and subsequent runoff into surface waters after heavy rains. In late May 1994 after a heavy rain, Nemacur applied to a course in Hollywood, Broward County, apparently washed into the C-10 Canal and killed thousands of fish. The fish included a 35-pound snook, a state species of special concern. A week earlier, some ducks had been killed in Plantation. In July 1993, an incident occurred in Miami when heavy rain washed Nemacur into waterways and killed thousands of fish and some birds. Leaching of Nemacur into groundwater is a serious concern. The U.S. Golf Association found fenamiphos contaminating 9 of 24 monitoring wells tested in Florida. The U.S. EPA has expressed concern about contamination of drinking water by fenamiphos since 1990. A geologist for the Florida Department of Environmental Protection has recommended a ban on the use of Nemacur in sandy ridge soils until methods to establish setbacks from wellfields are determined. The manufacturer of Nemacur has agreed to conduct a groundwater monitoring study in Florida in 1995 (Zaneski 1994b). In South Florida, the threat of Nemacur is amplified in Subregion 9 because of the concentration of golf courses and the region's heavy rainfall in the summer, combined with the high solubility of the chemical.

To reduce herbicide use and potential contaminant runoff to surface waters, the Florida Department of Transportation stopped the use of broadcast spraying of herbicides statewide as of July 1, 1994 (L. Burnett, FDOT, pers. comm.).

Preservation and Restoration of Natural Areas

The natural habitats of the Lower East Coast, now scattered in fragments within the urban/agricultural landscape, are so reduced in extent that examples of any natural community in good condition are considered environmentally sensitive areas. Despite the dramatic reduction in natural lands, active land management contributed much towards their preservation in recent years. In 1991 the Metro-Dade County Park and Recreation Department began active management of the 6,000 acres of natural areas under its jurisdiction (McHargue and Hammer 1994). Hurricane Andrew, however, devastated areas of native plant communities in southern Dade County, reversing the progress and creating severe threats especially to upland hammocks and pinelands. Hardwood hammocks are being invaded by non-native species and some native vines at an unprecedented rate. If left unchecked these invasive exotics will drastically alter hammock composition and structure (Flynn 1994; Gann-Matzen 1994; Klein, undated; McHargue and Hammer 1994). Most native pines that survived the storm have been infested by pine bark beetles and killed by an associated fungus (Dade Co. DERM 1993a, 1994b; Dade Co. Park & Rec. Dep. 1994). The hurricane demonstrated that effective management is critical to the long-term maintenance of natural areas in the urban environment. Natural areas are not as resilient to storm disturbance as they were formerly because urban development has reduced the amount of native seed and, through landscape plantings and formation of new habitat (cleared land, canal banks, drained wetlands, etc.), has created an enormous seed bank of invasive species. Some foresters speculate that the general lowering of the water table in southern Dade County had stressed the pines before the storm, making them more susceptible to disease following the storm. Fire prevention also has worked against the long-term maintenance of pineland, which is a fire climax community. Small pines are reappearing in many of the areas that lost their pines.

Destruction of the hammocks by development was reported decades ago (Alexander 1958; Phillips 1940). Dade County has lost 98% of its original pineland-hammock landscape, most of it destroyed by logging, urban development, or agriculture, most rapidly between 1940 and 1970 (Loope et al. 1979; Snyder 1986). Half (2200

acres) of the remaining pineland is in private ownership. 350 acres of hammock are privately owned. Of the endangered plant species in Dade County, 70% are located on private lands (Klein, undated). The county's 10-year covenant program for protecting privately owned natural areas, under which landowners receive a tax exemption, has not been entirely successful [DERM undated (c)]. Only 177 acres of land, including some pineland, are under the program. Covenants are renewable at the end of 10 years, and existing penalties do not adequately prevent land from being removed from the program before the end of the 10 years and sold for development. Hurricane Andrew has caused some privately owned pineland under the covenant program to be removed prematurely because of loss of standing pines. Pines might have regenerated on some of this land had it not been cleared by landowners giving up their covenant agreements.

Urban development has also eliminated most scrub habitat. Palm Beach County has lost 95% of its Atlantic Coastal scrub habitat. The largest and most diverse tract that remains is the 249-acre Yamato Scrub in the south part of the county along I-95. In 1989, this tract, then proposed for development, was recommended as a scrub preserve (Fernald 1989). It is currently on the county's list for acquisition as environmentally sensitive land (Palm Beach Co. DERM undated, 1991). A policy statement on growth management in Palm Beach County recommended permanent protection for native ecosystems, restoration of those already damaged, and protection and acquisition of land for conservation and recreation (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988b).

All three counties have recognized the loss of natural areas as a critical issue and have programs to purchase sensitive lands for preservation. Many of these lands protect populations of endangered plants; other lands, such as those in mitigation land banks, are restored to native vegetation. Some of these purchases are arranged through the state Conservation and Recreation Lands Program (CARL). The state also has an ongoing program of restoring natural native vegetation in its state parks.

Several county, state, and cooperative efforts have been initiated in hurricane-damaged areas of Dade County and also in areas that serve as mitigation banks. State and county governments have undertaken a number of natural community restoration projects, many of which were drastically altered or accelerated in Dade County by Hurricane Andrew. The restoration project at storm-ravaged Cape Florida State Recreation Area on Key Biscayne may be the largest ever undertaken in the U.S. (FDEP 1993). The Dade County program to restore hurricane-damaged hammocks is the largest local natural areas restoration project in the country (M. Gregg, Dade Co. PRD, pers. comm.). All these efforts include intensive removal of invasive non-native species; fostering remnant mangrove, coastal strand, wetland, and hammock communities; and extensive planting of native vegetation. However, well documented restoration methodologies are lacking for South Florida vegetation communities. Planting experiments and adequate monitoring and documentation from which to develop better methodologies for future projects may not be conducted for lack of funds and in some cases lack of understanding of the need by decision makers in the agencies involved.

It must be recognized that remnants of natural communities, even though preserved or restored, are subject to continued stress because of fire suppression, alteration of natural hydrology, exotics invasion, and other factors. For instance, eradication of exotics will be a constant task because of persistent invasion from surrounding areas. Natural areas require management in perpetuity (Gann-Matzen 1994).

Invasive Nonindigenous Species

Aggressive non-native plant species such as melaleuca, Brazilian pepper, and Australian pine have spread beyond any possibility of mechanical control. It was concluded in 1980 that neither the technology nor the funds existed to eradicate the melaleuca present in Florida at that time (Woodall 1980). Existence of vast numbers of centers of distribution (or foci) of exotic plants makes their total eradication almost impossible (LaRoche and Ferriter 1992). The most effective means of controlling the spread of melaleuca is eradication of the most isolated seed trees, or outliers (Browder and Schroeder 1980; Woodall 1980), which are the foci of distribution. This would most likely result in successful control of many exotics in the urban areas of Subregion 9.

Invasive exotic plants are of much ecological concern because they have undergone large population explosions and formed monocultures that out-compete native species (Alexander and Crook 1984). Loxahatchee National Wildlife Refuge has one of the most severe infestations of melaleuca because of its proximity to numerous urban plantings made in the Palm Beaches (OTA 1993). Biological controls under development are the only real hope of halting the destruction of native landscapes and plant communities by melaleuca encroachment. Meanwhile, other species have escaped into the environment and pose threats to natural areas. Additional species continue to be introduced into the environment of the Lower East Coast by the nursery, pet, and aquarium trades. The magnitude of its international trade makes Miami the port of entry for many exotic introductions. Extremely large numbers of plants (330 million in 1990) and animals pass through Miami International Airport each year, most of these originating in Latin America. Of all plant shipments into the U.S., 85% pass through Miami (OTA 1993).

The importation and sale of non-native species is largely uncontrolled. There is no mechanism in place for screening and restricting the importation of new invaders. The focus of the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS) is on the importation of species that are risks to agricultural activities, not those that are risks to natural communities. The U.S. Fish and Wildlife Service, through the Lacey Act, prevents the entry of a short list of "injurious" taxa: 2 families, 13 genera, and 6 species. Efforts by the Service to add species to the Lacey Act have met successful opposition from the hobby trade. The Florida Division of Plant Industry, which sets standards for the nursery trade, makes no attempt to judge ornamental plants for "weediness" or invasive tendencies.

Many species, in addition to the few that are well known, pose threats to natural areas. Many of these have been identified by the EPPC. There is little, if any, government oversight on the sale and distribution of species identified as invasive problem species in Florida by the EPPC.

Scientifically based criteria have not been developed for screening nonindigenous species to support possible future controls. A protocol is needed to help set priorities for management measures at all possible stages--all the way from restrictions on importation, propagation, and sale to removal or biological control. Except for melaleuca and a few other species, the spread of invasive species is not being monitored.

Despite several successful cooperative activities concerning high-profile species such as melaleuca, there is a lack of a coordinated approach to the generic problem of invasive non-native species. Needed is the appointment of lead agencies and personnel at all governmental levels (federal, state, and local) to develop a coordinated approach that includes management initiatives and supportive research.

Loss of Habitat for Protected and Other Native Species

The amount of protected habitat for threatened and endangered species in Subregion 9 is so small that it does not guarantee the future of these species. Human activities have destroyed over 95% of Palm Beach County's scrub habitat since the turn of the century; what remains is fragmented and surrounded by developed or disturbed land. Large areas of coastal Palm Beach County that historically supported scrub communities are no longer recognizable as scrub soils and are now designated as urban lands or other unnatural substrates in soil surveys (Fernald 1989). Scrub habitat contains a high proportion of endemic plants; in Atlantic coastal scrub, 37% of the total species are endemic (Lovestrand 1990). Remaining pineland habitat is becoming so fragmented that it soon may not adequately support pineland fauna such as the pine warbler. Pine rockland plants are considered rare because of habitat loss (DERM 1994b). This habitat is designated on the Florida Natural Areas Inventory as imperiled both globally and in the state of Florida (Dade Co.Park & Recreation Dept. 1994; Gann-Matzen 1994). It is possible that many of the endemic plant taxa of the pinelands will be lost because only about half of the species are protected in Everglades National Park (Snyder 1986). A study of pineland species richness showed substantial variation among the study sites, indicating that the remaining fragments of pineland are extremely important in preserving biological diversity. In addition to habitat loss to development, the lack of adequate fire management threatens the viability of pineland habitat (Doren et al. 1993; Loope et al. 1979).

Destruction of natural cover is cited as a major factor in the reduction of native amphibian and reptile populations (Wilson and Porras 1983). The greatest threat to gopher tortoise conservation is extensive land alteration that accompanies urbanization (Cox et al. 1987). The Florida mastiff bat is considered endangered by the state of Florida partly because of loss of native forested habitat. To prevent further bat population decrease, it was recommended in 1989 that steps be taken to preserve remaining pine, live oak, and tropical hardwood hammock habitat in Dade and Broward counties (Robson 1989). The FG&FWFC developed a system that ranked the 668 regularly occurring vertebrate taxa in Florida according to biological vulnerability and state of knowledge of distribution, population trends, limiting factors, and conservation efforts. These rankings demonstrated the high relative importance of coastal regions, especially for reptiles, birds, and mammals. Coastal uplands (beach strands and maritime hammocks), habitats now almost totally lost in Subregion 9, stood out as important habitat for large numbers of vulnerable taxa (Millsap et al. 1990).

Many of the natural area land purchases in Subregion 9 are made to preserve remnant populations of endangered plants. Conflicts between development and protected species habitat are almost a daily occurrence in the urbanized area. Incidents of alligators invading subdivisions are common. A recent incident, however, involved an American crocodile that appeared in a new upscale estate/golf course development in South Dade County and had to be relocated because of fear for the safety of the residents. A crocodile population is established in the canal system of the Turkey Point Power Plant in the vicinity of the development.

Limited Federal Responsibility

The federal government has limited jurisdiction over factors relevant to South Florida Ecosystem Restoration in the urban and agricultural areas of the Lower East Coast. The U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the U. S. Department of Agriculture, the U.S. Army Corps of Engineers, and NOAA, through Sea Grant and the National Marine Fisheries Service, have various levels of research, land stewardship, or regulatory responsibilities in this area. Some of these activities are handled through grants to state and local agencies. The state also has some oversight or regulatory responsibility (e.g. Florida Department of Environmental Protection, FG&FWFC, FDACS, Florida Department of Community Affairs), but primary responsibilities reside with a multitude of municipal, county, and regional governmental and quasi-governmental agencies, in addition to many special taxing districts. The number of municipalities that control land use just in the Biscayne Bay planning area totals 32 (Alleman et al. 1994). A serious obstacle to solving growth problems is the absence of formal political institutions or a coordinated approach to address the entire range of issues and their cumulative impacts. This was reported specifically for Palm Beach County (Joint Cent. Environ. Urban Problems and FAU Instit. Gov. 1988a,b) but applies to all of Subregion 9. The federal government does not always know what state and local governments are planning that could affect the Restoration effort. Perhaps even more importantly, there is no central knowledge of ways that the federal government itself, through laws and policies in many agencies, may be affecting the restoration of South Florida Ecosystems, either positively or negatively.

Lack of Understanding About the Environment by Urban Residents

The great diversity of the Subregion 9 population (e.g., many different races and income levels, large number of non-native residents, many different tourist groups) makes it difficult for scientists or managers to use only one message to promote environmental protection, wildlife preservation, or water conservation. Each group looks at the environment and its impact on the environment with a different perspective and responds differently (Duda 1987). It is often difficult for residents to understand environmental changes in the coastal area because the direct cause may be many miles away (Browder et al., undated). Also, many residents have lived in South Florida for such a short time that they do not understand its environment or its problems (Gleason 1984). For example, the Hispanic population of Dade County grew by 64% during 1980-90; that of Broward grew by 169% (SFRPC undated). Recognizing this, SFWMD has initiated an outreach program directed at the Hispanic community of Dade County to inform that community about South Florida's water resources and how it can help protect these resources (SFWMD 1994).

Surveys indicate most homeowners consider wildlife and natural habitats in urban areas very important (Duda 1987). Specifically as related to gopher tortoise conservation, the FG&FWFC considers protection and management of preserves in urban areas a very valuable method of education. Establishing effective education programs as part of long-term goals for tortoise protection areas is an important management consideration (Cox et al. 1987). This applies to other species as well.

OBJECTIVES

The primary goal of proposed research in Subregion 9 is to determine ways to reduce or reverse the impacts of the area's population growth and continuing land development on the natural systems of South Florida and to enhance the expected benefits of the South Florida Ecosystem Restoration to the quality of life in the metropolitan and rural areas. The objectives are:

- Improve the natural beauty, conditions for human health, and quality of life on the Lower East Coast.
- Reduce the dependence of the metropolitan and agricultural areas on the Everglades/Water Conservation Area water and manage the water budgets of the natural and the developed areas for their mutual benefit.
    - Conserve and improve the quality of locally generated runoff from the metropolitan and agricultural areas by incorporating latest technologies for more efficient water utilization, such as backpumping reservoirs, aquifer storage and recovery, and stormwater treatment areas, while providing the opportunity to supplement clean water delivery to the Water Conservation Areas and Everglades National Park for hydroperiod restoration.
- Restore the hydrodynamics of the aquifer by restoring the water table ridge so groundwater flows both east to the sea and west to the Everglades.
    - Reduce dry season groundwater recession rates.
    - Improve the hydroperiods of remaining over-drained wetlands.
- Contain urban and agricultural development to avoid expansion into wetlands that constrains the ability to restore predrainage hydroperiods and hydropatterns in the Everglades, while maintaining flood control and water supply functions of the Central and Southern Florida Project.
    - Establish buffer areas between the East Coast Protective Levee and urban and agricultural areas.
- Reestablish and maintain clean, fishable and swimmable conditions throughout urban and agricultural waters.
    - Restore and revitalize estuarine and near-coastal waters influenced by the Lower East Coast, including the Intracoastal Waterway, State Aquatic Preserves, the Miami River, Lake Worth, Biscayne Bay, and northeastern Florida Bay.
    - Restore a volume, timing, and spatial distribution of freshwater flow to estuaries in relation to rainfall that more resembles that existing under predrainage conditions.
- Control all invasive nonindigenous species now established in South Florida outside of cultivation and prevent any new colonizations.

- Ensure that sufficient protected habitat, free of invasive exotic species, exists within the urban and agricultural areas to sustain genetically viable populations of native plants and animals, including threatened and endangered species, in order to maintain overall biodiversity within the region.

    - Establish strategically placed mitigation banks of large, contiguous blocks of natural and enhanced or restored habitats and interconnecting corridors.

    - Establish greenbelts to serve as wildlife corridors, aquifer recharge areas, and water preserves throughout the urban subregion by connecting existing natural habitats and potentially restorable habitats through land acquisition and mitigation banking.

APPROACH

Most of the major issues presented in this report are addressed by the three counties in their comprehensive master plans and other planning documents (Broward Co. Bd. Commissioners 1989a,b, 1993a,b; Metro-Dade Plan. Dept. 1988a,b, 1989, 1993). Municipal and county governments carry out many activities related to these issues and restoration interests of the Federal Task Force (Appendix A), and there is an outstanding base of expertise in these agencies crucial to the implementation of federal restoration plans. Because of strong local efforts, federal plans concerning research to support the above objectives must be coordinated with local governments, as well as environmental groups, to ensure that: (1) the South Florida Ecosystem Restoration effort contributes to planned or ongoing restoration efforts by these groups, (2) the South Florida Ecosystem Restoration effort results in direct environmental benefits to the Lower East Coast, and (3) planned or ongoing activities by these groups contribute to and enhance the South Florida Ecosystem Restoration effort. Following are the research recommendations for Subregion 9:

Comprehensive Program Planning Evaluations (These could be initiated by conducting workshops.)

- Determine and catalogue what research is being done or planned that relates to and supports the South Florida Ecosystem Restoration effort.
    - Identify lead agencies and individuals.
    - Identify research needed to support efforts or to make efforts more beneficial to the overall South Florida Ecosystem Restoration effort.

- Conduct a "Federal Consistency Study" to determine present or potential influences of federal government activities on South Florida Ecosystem Restoration.
    - Compile an annotated list of the federal government agencies, programs, and laws that, through regulations, grants, tax incentives, or otherwise, undermine federal efforts to restore the South Florida Ecosystem.
    - Identify federal programs that might be used to enhance the South Florida Ecosystem Restoration effort.
    - Give particular emphasis to factors that influence land use planning, zoning, and development decisions that result in encroachment of urban or agricultural development into wetlands and urban development into agricultural lands.

- Develop the same information as above for regional, state, and local agencies, programs, and laws.

Critical Lands

- Conduct a short interagency study, the U.S. Fish and Wildlife Service having the lead, to identify critical lands that should be preserved to support South Florida Ecosystem Restoration.

- Develop a digitized map with information layers in a GIS framework for use in establishing mitigation banks and investigating the feasibility of land acquisition or other habitat protection measures. Criteria that should be used include: habitat value for federally listed threatened and endangered species and state species of special concern (particularly replacement of short-hydroperiod wetlands needed by wading birds), present value of the land for aquifer recharge, and potential usefulness of the land for water reserves.
- Consider the potential effect on water supplies if the land were developed and development resulted in a general lowering of the water table.

- To aid the above study, conduct a short-term, quantitative analysis to determine, from a water supply and South Florida Ecosystem Restoration perspective, how various alternative scenarios of future land use and associated local water management in presently undeveloped wetlands between the urban east coast and the Water Conservation Areas and Everglades National Park (hereafter referred to as "The Buffer Lands") would affect water supply and water management in support of ecosystem restoration.
  - Determine the impacts of full or partial development of these lands. Include testing of the "worst case" scenario of full residential and/or commercial development.
  - Evaluate potential use of these lands for stormwater treatment, aquifer recharge, wildlife support, and compatible outdoor, nonstructured, low-impact recreational activities.
  - Use the latest version of the South Florida Water Management Model, the Natural System corollary of that model, and other quantitative analytical tools.

- Using the above information, evaluate the interaction between natural, urban, and agricultural systems.
  - Determine the critical feedback linkages of the natural system to urban and agricultural systems and vice versa.
  - Determine the landscape configuration that will allow healthy natural systems and urban and agricultural systems to coexist.
  - Determine how the natural system and its benefits to humans will be impacted by different population levels and landuse configurations.

- To further aid the selection of critical lands, conduct a GAP study for the Lower East Coast.
  - In a GIS framework, overlay spatial data on coverage of various plant communities, habitat of endangered and threatened species and other species of special interest, public lands, and lands covered by covenants.
  - Determine the gaps in species protection.

Quantity and Timing of Freshwater Flow to Estuaries

- Model the effect of various proposed Canal C-111 redesign alternatives (in the GRR) on water flow to Manatee Bay and Barnes Sound.

- Model the effect of various proposed Canal C-111 redesign alternatives (in the GRR) on water flow to northeastern Florida Bay across Canal C-111.

- Estimate the predrainage salinity patterns in Biscayne Bay by retrospective analyses of bottom sediments (i.e. foraminifera shells or diatom tests) and application of a natural system hydrologic model, refined and specially adapted to this use.

- Collect the required field data to calibrate the relationship between stage and discharge in canals discharging to Biscayne Bay and other coastal waters of the Lower East Coast.
  - Recalculate historic flows based on the new calibration and existing time series of stage data.
  - Install continuous stage recording instruments in canals lacking this instrumentation.

- Map salinity patterns in Biscayne Bay under a range of freshwater inflow rates, and use this information to develop and calibrate a hydrodynamic model to relate freshwater discharges to salinity patterns in Biscayne Bay.

- Develop and apply a methodology to test various scenarios of use of the Buffer Lands discussed above and associated canal operations for their effect on the quantity, timing, and quality of freshwater discharges to Biscayne Bay (adapt the South Florida Water Management Model to this use).
  - Use this information to design a structural configuration and operational strategy that would reestablish a more natural seasonal pattern of freshwater flow to Biscayne Bay.
  - Use output from the Natural System Model and any available information relating freshwater flows to salinities for general guidelines concerning the natural seasonal pattern in relation to rainfall.

- Determine ecological, hydrologic, and economic impacts of redirecting a portion of stormwater runoff to proposed catchment areas of western Subregion 9 rather than to the coast.

Surface Water and Sediment Quality

- Compile and synthesize the information necessary to reevaluate, update, and customize existing water quality standards and monitoring activities from the standpoint of the unique chemistry of South Florida soils and waters and from the standpoint of current local practices associated with agricultural activities, lawn care and maintenance, aquatic weed control, golf course maintenance, local manufacturing, etc. Determine the answers to such questions as:
  - Are the right contaminants being measured, given current South Florida application practices?
  - For some pollutants, such as nitrogen and phosphorus, are the thresholds for environmental damage appropriate, given the natural concentrations of these constituents in South Florida's fresh waters and coastal waters?
  - For contaminants such as heavy metals, PAHs, and synthetic organic chemicals, are the thresholds for environmental damage appropriate, given the relative low adsorbance characteristics of constituents of South Florida fresh and coastal waters (i.e., low concentrations of clay particles and organics that bind heavy metals and organic chemicals and make them less available)?
  - Finally, should water quality monitoring include biological indicators, since living organisms integrate the biological effects of all stressors? Could a suite of biological indicators be developed for routine use? How can biomonitoring be best integrated with chemical analyses to determine ecological health?

- Quantify the applications of pesticides, herbicides, and other xenobiotic materials on residential and agricultural areas, golf courses, and public lands.

- Investigate methods of reducing pesticide and herbicide applications to golf courses and other urban landscapes, including use of alternative landscape materials and designs.

- Determine the concentration and loading of various pollutants, including nutrients and contaminants, in canal discharges and direct (pipe) discharges to Biscayne Bay and other coastal water bodies.
  - Identify hot spots, in terms of point source or nonpoint discharges of pollutants, including sewage.
  - Compare the quality (pollutant concentrations) of water entering the developed part of each county at the boundary of the Water Conservation Areas and water exiting the county into coastal waters through the major canals (Miami; North New River; Hillsboro; West Palm Beach; and L-31N, which exits through C-111).
  - Use the above information to help determine total maximum daily loads (TMDLs) and establish pollution load reduction goals (PLRGs) in compliance with federal (EPA) and state (FDEP) water quality standards.

- Recommend that the State design its non-point source program toward staying within the established TMDLs. (See Section 303D of the Clean Water Act.)
- Determine the significance of seasonal runoff and storms in controlling rates of production in coastal waters.

- Determine the ecological impacts on surface water and biota of pesticides and fertilizers used on golf courses.

- Conduct research on biological effects of pollutants in subtropical estuaries (e.g., examine the increase in occurrence of cellular micronuclei observed with pollutant exposure).

- Support continued research to develop a water quality criterion for transparency to protect benthic communities, such as seagrass.

- Support cooperative surveys of sediment toxicity in Biscayne Bay.

- Support continued development of toxicity and mutagenicity screening techniques to reduce expenses of sampling and chemical analyses.

- Investigate use of an alternative (e.g., coliphage) to fecal coliform bacteria as an indicator of sewage-associated pathogens, given the rapid destruction of fecal coliforms in subtropical marine waters, and evaluate the appropriateness of sewage contamination standards for the coastal waters of Subregion 9.

- Organize a contaminants committee that would work to help focus research and monitoring relative to contaminants, reduce redundancy in monitoring programs, achieve consistency in data collection protocols, and reduce pollutant loads at the local community level.

- Determine the water quality impacts of redirecting urban stormwater runoff into natural areas.

- Evaluate the use of the Buffer Lands in Palm Beach, Broward, and Dade County for the treatment of storm water runoff to improve water quality of future discharges to the Everglades, Florida Bay, and Biscayne Bay.
  - Evaluate the effect of this usage on the Biscayne Aquifer from the standpoint of both water quantity and quality.
  - View the concept in terms of water supply, wetlands, wildlife, and human health.

Drinking Water Quality

- Determine the feasibility of using a water management approach compatible with the South Florida Ecosystem Restoration Program to reduce trihalomethane formation in treatment of drinking water supplies by lowering the concentration of precursors in raw water supplies.
  - Estimate the potential cost savings of implementing such an approach.
  - Conduct additional investigations, possibly including field studies and experiments, to better quantify the potential improvements and savings.

Water Consumption

- Investigate the attitudes of homeowners, professional landscapers, and nurserymen to determine the most effective methods of promoting use of xeriscape landscaping with native plants. Non-native species suitable for xeriscape landscaping are the same species that are most likely to become invasive in South Florida disturbed sites and natural areas; promotion of xeriscape landscaping with these plants will exacerbate the problem of invasive non-natives.

- Investigate how local government ordinances influence (promote/hinder) use of native xeriscaping.

- Prepare countywide comprehensive plans for reuse of treated wastewater.
  - Develop pilot programs to investigate and demonstrate wastewater reuse on different substrates, including rockland sites, and particularly on golf courses, parks, and public facility grounds.
  - Quantify the potential benefits of water reuse to the future water supply of Subregion 9.
  - Using GIS techniques, locate and quantify suitable lands and wastewater treatment facilities.
  - Determine the influence of environmental and health regulations on water reuse.
  - Examine the effects of wastewater reuse on groundwater and surface water quality.

- Investigate less intensive water use for golf course grass and other landscaping.

Preservation and Restoration of Natural Areas, Wildlife Corridors, and Other Areas of Connectivity

- Support research to guide state and local efforts to identify and purchase or otherwise preserve ecologically endangered lands.

- Support easements for private lands by providing funds and incentives to counties for acquisition of titles or permanent development rights to preserve natural areas presently in private ownership. Emphasize acquisition of pineland, with or without pine stands, as well as wetlands.

- Compile a comprehensive list of public lands in Subregion 9 in need of restoration, including what is required to restore and maintain each tract.

- Support research needed to develop standard procedures for successful restoration of natural areas.
  - Methods to determine appropriate siting conditions (e.g., soil contours, depth of saltwater/freshwater lens interface) for restoration/creation of wetlands.
  - Efficient propagation techniques for native plants; e.g., seed germination.
  - Establishment/maintenance of nurseries to provide plants for restoration.
  - Optimum reforestation/revegetation strategies (e.g., to achieve uneven age structure in pinelands).
  - Urban fire techniques appropriate for use in Subregion 9.

- Support monitoring and research in conjunction with restoration of parks and private lands (hammocks, pineland, mangroves).
  - Life history and reproduction of endemic plants of pine rocklands and scrub habitat.
  - Comparative, quantitative vegetation analyses of remaining hammocks to characterize and catalogue them by species composition, species dominants, and spatial patterns of species distributions to provide information needed to guide management activities (e.g., to prevent degradation from nearby inappropriate landscape plantings).
  - Restoration of the hydric components of pine rocklands and hammocks (e.g., pineland/prairie ecotones).
  - Impact of fragmentation on restored areas and of potential benefits of connectivity among restored areas and between them and proposed Buffer Lands.

- Conduct a GIS analysis of the urban Lower East Coast in the context of surrounding natural areas and endangered species populations.
  - Identify potential pathways for connecting all or many remaining natural areas into a greenbelt/wildlife corridor and linking these to the proposed buffer areas, using opportunities such as existing canal banks and railroad rights of way or undeveloped property in critical locations, even if disturbed.
  - Identify wetland sites and their soils and history of land use (i.e., whether farmed or not).

- Support the development of comprehensive greenway plans and demonstration projects currently being organized in all three counties.
  - Provide federal funding for broad-scope greenbelt projects in each county.
  - Require that native species appropriate to the local natural areas are used for all plantings along federally financed trails.
  - Emphasize use of trails as wildlife corridors.

- Support research on wildlife and human ecology effects of existing and future wildlife corridors; e.g., effect of corridor size on wildlife movements.

- Conduct an urban wildlife survey to compare wildlife support values of various existing landscapes within the urban setting for fauna such as resident, migrant, and wintering birds; herpetofauna such as lizards; and insects such as butterflies.

Protected Species

- Support research to collect information needed on species that are candidates for federal listing as threatened or endangered, especially those threatened by imminent habitat loss in rapidly developing areas.

- Assist Dade County with development and implementation of a restoration plan for the Richmond Pineland Preserve, which includes federally owned land (U.S. Coast Guard, U.S. Customs, and U.S. Navy) in addition to land owned by the Dade County Park and Recreation Department and the University of Miami.

- Assist Dade County with development and implementation of restoration plans for other natural areas.

- Support continued study of manatee behavior and migration patterns in the Biscayne Bay system.

- Support quantitative studies of wildlife use in remaining wetlands of southeast Dade County and interior western portions of all three counties.

- Develop a curriculum for training courses for certification of contractors bidding on Army Corps of Engineers construction projects that could affect species of environmental concern, such as plants and animals on federal and state listings of endangered and threatened species.

Invasive Non-native Species

- Conduct horticultural research to develop sterile cultivars of the more popular landscape plants, such as poinciana and the many ornamental *Ficus* species, that are showing tendencies of becoming invasive as landscape plantings increase and the acreage--and resultant seed bank--of native species decreases.

- Starting with the EPPC list, develop a consistent, effective methodology for ranking non-native plant species for their invasive tendencies in the South Florida environment.
  - Identify the greatest immediate threats as candidates for (1) major short-term, intensive, localized mechanical control efforts and (2) longer term biological control efforts. This will provide more lead time for developing environmentally safe, effective biological controls before each invasive species causes major damage to natural areas and wildlife habitat.

- Develop an effective, scientifically based approach to screening for potential invasive tendencies (1) plant materials entering South Florida and (2) plant materials already in the landscape trade, but not yet observed outside cultivation.

- Design an approach to preventing future invasions by the above species, considering a mix of regulatory, incentive, and public education options.

Education and Sociology

- Conduct and/or support outreach programs to educate urban residents and tourists about methods to reduce their impact on the South Florida ecosystem. An example is SFWMD's program on water use for the Hispanic community.

- Conduct and/or support research on the attitudes of the region's diverse groups of urban residents, private landowners, and tourists about wildlife, habitat, environmental protection, and water conservation and methods to influence those attitudes.

- Conduct and/or support programs to teach citizens how they can influence government actions on land use and environmental issues related to South Florida.

APPENDIX A

RESEARCH SUMMARIES

SUBREGION 9

Appendix A summarizes many of the research, monitoring, restoration, and evaluation projects that have been conducted or initiated in the Lower East Coast to address the issues identified in the main report. Generally, the projects listed in this appendix are limited to those conducted over the past 20 years. Earlier surveys and projects are discussed in the background section of the main report. The projects are categorized by topic as listed below. Within each topic, projects are organized under four headings: Palm Beach County, Broward County, Dade County, and Region. The "Region" category contains programs that are cover more than one county; these may be regional, state, or national programs that include the Lower East Coast. Under each heading, projects are organized by the agency or organization conducting them.

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WATERSHED HYDROLOGY/WATER SUPPLY

PALM BEACH COUNTY

South Florida Water Management District.

Groundwater flow model. A three-dimensional groundwater flow model of the Surficial Aquifer System in eastern Palm Beach Co. was developed in 1989. Originally two separate models for the northeast and southeast county, these have been combined into a single model that now incorporates portions of Broward and Martin counties. The model performs, on a monthly time step a continuous yearly simulation using historical data including pumpage, rainfall, and evapotranspiration. The model is used for predictive purposes; e.g. to determine water demands of the Lake Worth Drainage District.

Documentation:
Planning Department Staff, SFWMD. 1993. Working document in support of the Lower East Coast Regional Water Supply Plan. Draft report, appendices, and technical information. Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Shine, M.J., D.G.J. Padgett, and W.M. Barfknecht. 1989. Ground water resource assessment in Palm Beach County, Florida. Technical Publication 89-4, Part II. Hydrogeology Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida. [need Part I]

Determination of drawdown zones of influence. The goal was to define areas of possible surface water impacts due to permitted withdrawals from existing municipal water supply wellfields. Maps were produced showing one-foot drawdown lines. Several wellfields were hydraulically connected to large surface water bodies or canals.

Documentation: Padgett, D.G.J. 1987. One foot drawdown zones of influence surrounding municipal water supply wellfields in Palm Beach County. Technical Memorandum. Hydrogeology Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Preliminary feasibility study of a wastewater reuse system for Palm Beach Co. A SFWMD evaluation found that Palm Beach Co. had the largest potential reuse size of any county in its district. Eastern Palm Beach Co. was selected for a case study because its large population, ample supply of wastewater, and large potential demand (i.e., numerous golf courses and large landscape areas). A design and cost analysis described the existing suppliers, existing users, design and cost of the network needed to link them, and necessary treatment system. A cost-effectiveness analysis determined associated costs and savings. The study indicated that only 13 of 84 potential users would find the system cost-effective. Few existing treatment plants or irrigation users would voluntarily participate in a wastewater reuse system because it would not be economically advantageous

Documentation: Adams, B.P., D.J. Sample, and L.C. Woehlcke. 1984. An evaluation of wastewater reuse policy options for the South Florida Water Management District. Technical Publication 84-6. Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Water supply plan for Palm Beach County.
[need document]

Documentation: Planning Department Staff, SFWMD. 1992. Dade County-Florida Keys Water Supply Background Document. Draft report and appendices. Planning Department, South Florida Water Management District, West Palm Beach, Florida.

BROWARD COUNTY

South Florida Water Management District

Water supply plan for Broward County. Proposed a system of 1,200 acres of reservoirs along the eastern edge of the WCAs.
[need document]

Documentation:
Planning Department Staff, SFWMD. 1992. Dade County-Florida Keys Water Supply Background Document. Draft report and appendices. Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Larsen and Associates. 1992. South Florida Limestone Mining Coalition Year 2050 Freshwater Lake Belt Plan. Larsen and Associates, Miami, Florida.

Groundwater flow model. A three-dimensional groundwater flow model of the Surficial Aquifer System in eastern Broward Co. was developed in 1992. The model performs, on a monthly time step a continuous yearly simulation using historical data including pumpage, rainfall, and evapotranspiration. The model is to be used for predictive purposes; e.g., evaluating potential impacts of the proposed Broward Co. North Regional Wellfield, and of the City of Deerfield Beach and Broward Co. 2A wellfields and their combined impact on the saline interface.

Documentation:
Planning Department Staff, SFWMD. 1993. Working document in support of the Lower East Coast Regional Water Supply Plan. Draft report, appendices, and technical information. Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Restrepo, J.I., C. Bevier, and D. Butler. 1992. A three-dimensional finite difference ground water flow model of the surficial aquifer system, Broward County, Florida. Technical Publication 92-05. Hydrogeology Division, Department of Research and Evaluation, South Florida Water Management District, West Palm Beach, Florida.

DADE COUNTY

South Florida Water Management District, Office of Government and Public Affairs, Miami Service Center.

Water supply plan for Dade County-Florida Keys. A background document compiled and evaluated available information on supply and use of the local water resources and its relationship to the District's water supply system. The background document includes: a description of relevant water supply goals, directives, and policies as they apply to water supply planning within Dade and Monroe Co.; a compilation and preliminary analysis of extensive data available on the area's water resources; an analysis to quantify present and future water demands, water use, and constraints on future water supply sources; and a preliminary analysis of water supply and conservation options. This information is being used to develop a water supply plan for the Dade Co.-Florida Keys area, scheduled for completion by 7/94.

Documentation: Planning Department Staff, SFWMD. 1992. Dade County-Florida Keys Water Supply Background Document. Draft report and appendices. Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Groundwater flow model. A three-dimensional groundwater flow model of the Surficial Aquifer System in eastern Dade Co. is being developed. The model performs, on a monthly time step a continuous yearly

simulation using historical data including pumpage, rainfall, and evapotranspiration. The model is to be used for predictive purposes.

Documentation: Planning Department Staff, SFWMD. 1993. Working document in support of the Lower East Coast Regional Water Supply Plan. Draft report, appendices, and technical information. Planning Department, South Florida Water Management District, West Palm Beach, Florida.

South Dade County Watershed Project (C-5245). Under contract to Univ. of Miami School of Architecture, Center of Community Design, to apply watershed approach to integrate land use development and resource protection by interactively coordinating local, state, and federal planning activities. Project is first step in developing comprehensive watershed plan for restoration and protection of Biscayne Bay. Objectives are to: 1) provide comprehensive understanding of relationships between land use in South Dade Co. and regional water management objectives; 2) build consensus among interests as to actions necessary to achieve water management objectives; and 3) select a hydrologic basin within South Dade Co. watershed for future study and development of demonstration project(s). Strategies will be initiated by a watershed planning workshop to build consensus on necessary actions. The workshop report will include discussion of all issues, inventory of all available data and data needs, and discussion of agency responsibilities. The existing watershed for Biscayne and Everglades National Parks will be delineated and mapped. A complete data inventory for the watershed will be prepared with descriptions and sources of data. Data analysis will include: 1) total existing and future wetland area; 2) total area by existing and future land use; 3) estimate of existing and future stormwater pollutant loadings; 4) estimate of existing and future total impervious area; 5) analysis of feasibility of using wetlands for pollution load and ranking of potential restoration sites; 6) feasibility of using urban stormwater BMPs for pollution load; 7) estimate of existing and future water storage capacities; 8) evaluation of non-structural alternatives. A summary report will establish impact of South Dade land use on regional water management objectives, recommend strategies for achieving those objectives in South Dade, and recommend a hydrologic basin within South Dade for future study.

Documentation: South Florida Water Management District. Undated(a). Exhibit "A," Statement of Work, South Dade County Watershed Project (C-5245). South Florida Water Management District, Miami Service Center, Miami, Florida.

U.S. Army Corps of Engineers, Jacksonville District.

Canal 111 re-evaluation. C-111 is in southeastern Dade Co. adjacent to the eastern boundary of Everglades National Park. The ENP Protection and Expansion Act of 1989 stipulated that the General Design Memorandum for project works within the C-111 basin include all measures feasible and consistent with the purposes of the project (maintain flood damage prevention in the basin) to protect natural values of ENP and that the report provide the status of natural resources of the basin and functionally related lands. The study had 4 objectives: restoration of historic hydrologic conditions in the C-111 basin, protection of natural values associated with ENP, elimination of damaging freshwater inflows to Manatee Bay/Barnes Sound, and maintenance of flood protection in the C-111 basin, east of L-31N and C-111.

Alternative plans were formulated and evaluated in coordination with SFWMD, ENP, and USFWS. The recommended plan consists of structural and non-structural modifications to existing project works, including acquisition of almost 12,000 acres of land in the basin. The SFWMD is responsible for acquiring critical water resource lands in the C-111 basin for the State of Florida Save Our Rivers Program. The purpose of this program is to acquire lands for water management, water supply, and conservation and protection of water resources. Approximately 27,850 acres have been acquired as part of the Southern Glades. Other tracts being pursued are the Frog Pond and the Rocky Glades. An interagency ecological

monitoring plan will be produced involving DOI, NOAA, USACOE, SFWMD, and the state of Florida. The majority of the study area will be outside the boundaries of Subregion 9.

Documentation: U.S. Army Corps of Engineers. 1994. Canal 111 (C-111) South Dade County, Florida. Final integrated general reevaluation report and environmental impact statement. Central and Southern Florida Project, U.S. Army Corps of Engineers, Jacksonville, District, Jacksonville, Florida.

Experimental Program of Modified Water Deliveries to ENP. PL 98-181 allows the minimum delivery schedule in the C-111 basin in South Dade Co. to be temporarily abandoned in order to test alternative plans for delivering water to the park. The first test started in 1985, and there have been 5 iterations of testing since then. Section 107 of PL 102-104 authorized continuation of the experimental program until implementation of modifications to the C&SF project.

Documentation: U.S. Army Corps of Engineers. 1994. Canal 111 (C-111) South Dade County, Florida. Final integrated general reevaluation report and environmental impact statement. Central and Southern Florida Project, U.S. Army Corps of Engineers, Jacksonville, District, Jacksonville, Florida.

Miami-Dade Water and Sewer Authority Department.

Wastewater reuse feasibility study. The WASAD conducted a feasibility study as mandated by state law. The uses for reclaimed water that were investigated were urban irrigation, agricultural irrigation, wetland application, aquifer recharge, saltwater barrier, power plant reuse, industrial reuse, and potable reuse. Technically, reuse is feasible. A minimal level of reuse is most technically feasible because of permitting and implementation concerns associated with agricultural and some other alternatives. All alternatives provide environmental benefits, including conserving potable water, postponing expansion of water supply, recharging aquifers, improving surface water quality, and saving fertilizer due to nutrient content of reclaimed water. The contractor recommended that WASAD proceed with an aggressive reuse program based on a "medium" reuse alternative consisting of 120 mgd of public access reuse (parks, golf courses, campuses, sports fields, agricultural lands), 30 mgd of saltwater intrusion control in the Central District by recharge of Snake Creek Canal, and 39 mgd of saltwater intrusion control in the South District by injection or wetlands restoration.

There are 2 major concerns with implementation of reuse: 1) vulnerability of the Biscayne aquifer to pollutants discharged on land surface, and 2) effluent from the Central and North District treatment plants has elevated chloride concentrations that could negatively impact irrigation reuse.

The application of reclaimed water to wetlands might restore hydrologically altered communities or create wetlands on former wetland sites. The study determined that the site with the greatest potential for wetland restoration was in South Dade in the Model Lands Basin.

Documentation: Post, Buckley, Schuh, & Jernigan, Inc. 1992. Wastewater reuse feasibility study. Volumes I and II (Appendices). Prepared for Miami-Dade Water and Sewer Authority Department, Metropolitan Dade County, Florida.

University of Miami/Florida International University.

South Dade planning studies. Design professionals, government officials, members of civic organizations, and residents attended a workshop to create plans for rebuilding the extensive hurricane-damaged area of South Dade Co. One of the priorities identified in the workshop was that water quality and quantity must be protected and controlled to sustain the supply of freshwater to urban, agricultural, and natural systems.

Documentation: University of Miami and Florida International University. 1992. The new South Dade planning charrette: from adversity to opportunity. School of Architecture, University of Miami, and School of Design, Florida International University, Miami, Florida.

U.S. Army Corps of Engineers.

Experimental water deliveries to Everglades National Park. An experiment began in July 1993 to increase water deliveries to Taylor Slough in ENP. The test will provide field data useful for evaluating alternatives to be included in the C-111 General Reevaluation Report and Environmental Impact Assessment. The test will continue for 2 years or until sufficient information is obtained to design a permanent solution to the problem of unnatural water flows to Taylor Slough and southeast ENP. The test is being conducted through an iterative procedure in which each step builds upon information obtained in previous tests. Some modeling will be done prior to the demonstration to identify hydrologic boundaries of the experimental deliveries. The experiment could be terminated if unacceptable human impacts result; e.g., to private lands east of ENP. Agriculture is a principal land use in the area east of ENP (i.e., East Everglades), including the Frog Pond (north of Highway 9336 and between C-111 and L-31W) and the Rocky Glades (along L-31N). Also, there is some residential development in the 8½-Square-Mile Area along the L-31N. The monitoring plan will evaluate: hydrologic effects of holding higher water elevations at S-176; adequacy of water availability within the C-111 basin to restore more normal water deliveries; hydrologic effects on Taylor slough of providing altered water deliveries through S-332; water quality conditions with and without altered water deliveries; effects on environmental resources,including endangered species (Cape Sable seaside sparrow), nesting birds, and vegetation; and effects on farming activities.

Documentation: U.S. Army Corps of Engineers. 1993. Experimental program of water deliveries to Everglades National Park, Taylor Slough iteration. Final environmental assessment. Central and Southern Florida Project, U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, Florida.

REGION

South Florida Water Management District.

Lower East Coast water supply plan. A working document was prepared that contained background material and preliminary evaluations of information related to supply and use of regional water resources and relationships of the regional source to localized supply systems in Palm Beach, Broward, Dade, Monroe, Collier, and Hendry counties. Evaluations are based on water supply and use, estimated demands, estimated environmental needs, and system constraints. These materials form the basis for development of a final plan that will identify preferred alternative(s) and other recommendations.

Documentation: Planning Department Staff, SFWMD. 1993. Working document in support of the Lower East Coast Regional Water Supply Plan. Draft report, appendices, and technical information. Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Water resources modeling. The District conducts intensive modeling research and evaluation to develop the best possible regional operational policies for the Lower East Coast and other subregions of South Florida. Large-scale models of both surface and groundwater are used to quantify how modifications to the hydrological system will affect water conditions and discharges. Results help decide changes that are needed in the present system to meet future needs. The South Florida Water Management Model (SFWMM) is a regional two-dimensional, integrated surface water-groundwater model used to assess the effects of management options in a large portion of South Florida, including Palm Beach, Broward, and

Dade counties. Information from this model is entered into more detailed models of the surficial aquifer systems in each of the counties. The South Florida Regional Routing Model (SFRRM) has been used since the late 1970s to analyze the Lake Okeechobee-Lower East Coast regional hydrologic system.

Documentation (examples):
MacVicar, T.K., T. VanLent, and A. Castro. 1984. South Florida water management model documentation report. Technical Publication 84-3. Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Planning Department Staff, SFWMD. 1993. Working document in support of the Lower East Coast Regional Water Supply Plan. Draft report, appendices, and technical information. Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Trimble, P. 1986. South Florida regional routing model. Technical Publication 86-3. Water Resources Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Analysis of water supply backpumping for the Lower East Coast. The basins selected for study were the West Palm Beach Canal C-51/L-8, North New River/C-13, Snake Creek Canal C-9, and Tamiami Canal basins. Impacts were assessed hydrologic conditions, economics, water quality, and model simulation of environmental conditions in WCAs and estuaries.

Documentation: South Florida Water Management District. 1982a. An analysis of water supply backpumping for the Lower East Coast planning area. Special Report (revised). Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

U.S. Geological Survey, Water Resources Division.

Water resources data collection. During each water year (October-September), the USGS obtains a large amount of data on Florida water resources. The data include records of stage, discharge, groundwater levels, and water quality of streams; and stage, contents, and water quality of lakes and groundwater wells. In Subregion 9, the data are from 19 surface water (canal) stations, in cooperation with many municipal, county, state, and other federal agencies in the Subregion. One station on the West Palm Beach Canal and another on the Miami Canal have records dating back to 1939. Since 1974, the Miami Canal station has been part of the National Stream Quality Accounting Network. Throughout Subregion 9, water level is monitored in almost 140 wells either by digital water-level recorders or satellite data collection platforms. Specific conductance and concentration of dissolved chloride are measured.

Documentation:
Haire, W.J., and C. Lietz. 1993. Water resources data - Florida, 1992. Volume 2B: South Florida ground water. Water-Data Report FL-92-2B. U.S. Geological Survey, Miami, Florida.
Haire, W.J., and C. Price. 1993. Water resources data - Florida, 1992. Volume 2A: South Florida surface water. Water-Data Report FL-92-2A. U.S. Geological Survey, Miami, Florida.

Evaluation of wastewater reuse policy options. The SFWMD identified potential users and suppliers of wastewater throughout its district and projected average wastewater flows for each county. The Lower East Coast counties of Palm Beach, Broward, and Dade represented 73% of the district's potential capacity for wastewater reuse. Palm Beach County alone represented 34%. Reuse could potentially contribute a substantial amount of additional water to the region but implementation is highly dependent on local conditions and would be economically advantageous to just a small to modest proportion of suppliers and users.

Documentation: Adams, B.P., D.J. Sample, and L.C. Woehlcke. 1984. An evaluation of wastewater reuse policy options for the South Florida Water Management District. Technical Publication 84-6. Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Joint Center for Environmental and Urban Problems.

Survey of wastewater reuse systems in South Florida. This study conducted in 1985 for the South Florida Water Management District identified all wastewater reuse systems in an area that included most of the state south of Ocala, gathered quantitative data on the systems and information on motivations for water reuse, and selected systems for further study. The use of wastewater was primarily an economic decision because it was a low-cost disposal method. Some of these systems were discontinued in favor of deep-well injection disposal when surface water discharge regulations became more stringent. For example, some providers discontinued reuse rather than meet regulations that restrict surface water discharge and require development of backup systems. The systems in operation in Subregion 9 at the time of the survey were:

Palm Beach County:

Boca Raton - A county plant discharges effluent to a lake system, which is used to irrigate a golf course, plant grounds, and the grounds of Century Village. The plant was due to go to deepwell injection in 1-2 years because it would exceed its permitted limit.

North Palm Beach - A Seacoast Utilities plant reused part of the effluent onsite to wash tanks and drive the chlorinator.

Palm Beach Gardens - Effluent from a Seacoast Utilities plant was used onsite to wash tanks and offsite via a closed canal system to irrigate a golf course. Water quality problems occurred at the end of the canal system, but nutrients in the wastewater cut the golf course's fertilizer costs.

Broward County:

Davie - Effluent from one treatment plant was discharged into a canal, from which residents could withdraw water for lawn irrigation. The plant was phased out when EPA and Florida DER asked that the canal discharge be discontinued. Effluent from another plant was used for onsite irrigation of plant grounds. This plant was due to be tied into Hollywood's system.

Plantation - A city plant discharged effluent to the Holloway Canal, from which residents withdrew irrigation water since about 1959. EPA was requiring the plant stop discharging to the canal by 1986, when the plant was to go to deepwell injection. A private plant discharged effluent to a lake and a canal system, from which residents and a condo association withdrew irrigation water. At the time of the survey, the plant was under a zero discharge order from EPA.

Sunrise - 3 city plants discharged effluent to ponds; water was withdrawn to irrigate golf courses. Another city plant discharged effluent into a pond behind the plant which was used for fishing; some effluent was used to wash down the plant. Deep well injection was to be used by all plants by 1985; reuse was no longer economically advantageous because additional percolation ponds were needed to prevent overflow. Effluent would be available to entities along the force main, but users would have to provide any additional treatment required. In 1982, the city council passed an ordinance that require all new golf courses to use effluent from the city's wastewater plants for irrigation; it requires that the effluent be used to irrigate new parks and arterial rights-of-ways; and encourages use of wastewater on existing golf courses and green spaces.

Tamarac - A city plant discharged wastewater to a lake system, which was used to irrigate a golf course.

Dade County:

Miami - Effluent from a private plant was discharged into a lake at a country club and used for irrigation. The plant was built to service the Aventura community because of a moratorium on

sewer connections in Dade Co. The plant was eventually deeded to Dade Co., and the sewage was discharged into the county system.

Documentation:
Joint Center for Environmental and Urban Problems. 1985b. South Florida's wastewater reuse systems. Phase one of a three phase project. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.
Joint Center for Environmental and Urban Problems. 1985c. South Florida's wastewater reuse systems. Phase two of a three phase project. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.
Joint Center for Environmental and Urban Problems. 1985d. South Florida's wastewater reuse systems. Final report. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.

South Florida Regional Planning Council/1000 Friends of Florida.

Plan for water retention areas. A 1991 conference on (Protecting South Florida's Water Resources - An Urban Agenda) recommended a system of regional retention areas to store and filter water. The reservoirs would extend along the eastern edge of the WCAs from the C-51 basin in western Palm Beach Co. to South Dade Co.

[need May 1991 proceedings]

National Audubon Society.

Proposal for water supply preserves. Proposes a series of marshes adjacent to the eastern boundaries of the WCAs and ENP, stair-stepped in elevation from north (highest) to south. These preserves would hold reclaimed water that is presently being routed to estuaries of the Lower East Coast. They would be located in conjunction with the primary east-west canals. The goal would be to return more natural hydrological timing to Everglades water delivery by replicating natural storage areas and releasing the water in a controlled manner that mimics the natural seasons.

Documentation: National Audubon Society. 1994. Report on water supply preserves. National Audubon Society, Everglades Restoration Campaign, Miami, Florida.

WELLFIELDS/GROUNDWATER QUALITY

PALM BEACH COUNTY

U.S. Geological Survey

Groundwater contamination assessment from Lantana landfill. A geophysical reconnaissance around perimeters of 12 active and abandoned landfills in Palm Beach Co. showed a low-resistivity area along the eastern boundary of the Lantana landfill. Surveys were conducted in 1985 to determine the extent of the leachate plume. Shallow water-table wells showed a hydraulic gradient to the east; groundwater movement was from the landfill site toward a lake to the east. Water quality samples were collected from 14 groundwater and 3 surface water sites. Lateral movement of leachate had occurred to a distance of 300 feet at a depth centered at 30 feet. Some vertical movement of leachate may have occurred into the lower zone of the surficial aquifer to a depth of about 70 feet.

Documentation: Russell, G.M., and A.L. Higer. 1988. Assessment of ground-water contamination near Lantana landfill, southeast Florida. Ground-water 26:156-164.

BROWARD COUNTY

City of Hollywood.

Quality of potential groundwater supplies. Investigations were initiated and aimed at developing new wellfields because of potential susceptibility to saline water intrusion during periods of low rainfall and high groundwater withdrawal and because of projected water supply shortfall. The studies involved evaluation of existing treatment facilities, development of conceptual designs of water system improvements, evaluation of other water sources for diversification of the water supply, and evaluation of the chemical properties and treatment needs of water from potential sources.

Documentation:
Metcalf & Eddy. 1992. Treatability study for the City of Hollywood Phase 1 - office studies.
Metcalf & Eddy and Berry & Calvin. 1992. Preliminary design report, City of Hollywood water treatment plant upgrade. Submitted to City of Hollywood, Florida.
Stone & Webster Engineering Corporation and Geraghty & Miller, Inc. 1988. 10-year drinking water supply and treatment plan, City of Hollywood, Florida. Volume I. Draft.

South Florida Water Management District.

Impact of a rockpit lake on groundwater quality. A common practice associated with urbanization is the digging of lakes to provide fill for homesites and to receive storm runoff from the development. The study site was a lake in north Broward Co. For one year, water samples were collected from the lake and adjacent groundwater, lake stage and water table elevation data were collected, and runoff from 3 separate storm events was analyzed. Lake sediments were also analyzed for lead content. Results showed that storm runoff to the lake could contain high concentrations of chloride, copper, lead, and nutrients. It appeared that lead was accumulating in the bottom sediments. There was a general increase in groundwater levels of some parameters such as specific conductance downgradient from the lake, but it could not be determined that the lake was the cause of the change.

Documentation: Weinberg, M., D. Reece, and D. Allman. 1980. Effect of urban stormwater runoff to a man-made lake on groundwater quality. Technical Publication 80-4. Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

DADE COUNTY

Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Planning and Evaluation Section (Monitoring program establishes baseline data and assesses impacts of land use on water quality)

Ambient groundwater monitoring. Samples network of 32 wells for monthly water level and bimonthly or quarterly physical parameters (Ph, conductivity, nutrients, major anions, minerals, inorganics, trace metals, organics, selected pesticides, and phenols). Program also includes well installation and surveying when necessary.

Documentation: Ignacio, C. 1994. Letter with tables to C. Goodyear dated February 22, 1994. Metropolitan Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Miami, Florida.

Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Planning and Evaluation Section, Agricultural Waste Program (Program monitors agricultural facilities that use large quantities of hazardous chemicals related to processing and production of various agricultural products. Program requires permits for such facilities and provides regular inspections to make sure that groundwater in wellfield protection areas is not polluted.)

Survey of pesticides used in West Wellfield study area in 1988. Listing of chemicals used or projected for use on major fruits, vegetables, and nursery stock, based on discussions with Dade Co. growers, extension personnel, ENP, IFAS, and Fl. Dept. Agric. & Consumer Services. A total of 78 different active ingredients were used or projected for use as insecticides/miticides, bactericides, fungicides, herbicides, or fumigants. 25 chemicals were commonly used and were the most frequently selected when a product was needed. 36 other chemicals were occasionally used. Some of the pesticides are used very frequently: an estimated 30 applications of insecticides and fungicides per year on nursery plants, 25 applications of insecticide per crop of corn, 24 applications of fungicide per crop of tomatoes; 20 applications of fungicides per crop of mangos.

Documentation: Dade County Department of Environmental Resources Management. Undated. Pesticides used in West Wellfield study area 1988. West Wellfield Subcommittee on Agriculture, Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Description of potential pollution point sources in the West Wellfield Interim Protection Area. Brief summary of agriculture in Dade Co.: Even with its expanding urban population, the county remains one of the U.S.'s top 100 agricultural counties. Over 80,000 acres were harvested in 1986-87. Climate allows farmers to grow high value crops of a diversity unrivaled in continental U.S., but also creates ideal conditions for proliferation of wide array of diseases and pests. Farmers rely heavily on pesticides, fertilizers, and also irrigation. The West Wellfield Protection Area contains about 5,000 acres of agriculture, with seasonal row crops predominating (4,430 acres) in a magnitude not seen in existing wellfields. Another 8,000 of land are potentially available for conversion to agriculture. The area also includes about 10,000 acres of residences, golf courses, schools, and parks where pesticides and fertilizers may be routinely applied. Overall in the 18 active Dade Co. wellfields, agriculture still represents a

relatively minor land use. Thus agricultural activities have not been subject to the level of regulatory controls governing urban sources.
Summary of pollution sources: Potential contamination sources are "point" (spills, leaks, or localized discharges) and "non-point" (application of fertilizers, pesticides, and other agrichemicals to soil and water bodies). Point sources are (these are more completely discussed in the July 1990 reference cited below): 1) storage of agrichemicals and other hazardous materials (underground, aboveground, container storage); 2) agriculture handling operations (mixing and loading, chemigation and fertigation, pesticide rinse water); 3) open wells; 4) liquid wastes (packing facility effluent, crop production wastewater, equipment cleaning/ repair); 5) solid wastes (empty pesticide containers, plastic mulch, manure, discarded produce). Agricultural Waste Program]

Documentation: Dade County Department of Environmental Resources Management, Planning and Evaluation Section. 1990. Agricultural and agrichemical-related operations within the West Wellfield Interim Protection Area: I. General introduction and description of potential point sources of water pollution. Report to the West Wellfield Policy Advisory Committee. June 25, 1990. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Summary of potential pollution point sources in the West Wellfield Interim Protection Area. Explains potential threats to drinking water quality and air quality from 7 sources, along with regulatory options:

1. Open, uncased agricultural wells. Between 1,000 and 2,000 such wells are thought to exist in crop areas within the West Wellfield. They can provide inadvertent or intentional drainage for excess storm and irrigation water and function as direct conduits for pollutants from spillages at agrichemical mixing sites or from effluent discharges from crop washing activities.
2. Storage of agrichemicals and other hazardous materials. Many agricultural operations, and also large landscape operations such as golf courses and schools, stockpile large quantities of chemicals and fuels. Unless containers are properly maintained and protected, spills and leaks can contaminate groundwater.
3. Liquid wastes generated ancillary to agriculture. These include equipment cleaning and repair on farms, golf courses, and other large landscape areas (waste oil, transmission fluid, waste from parts washing, etc.). Liquid waste is also produced by certain packing operations.
4. Pesticide residue and rinse water disposal. Residue and rinse water are generated by agriculture, lawn maintenance, homeowner use, golf courses, road and canal maintenance, parks, mosquito control, etc. Rinse water can be discharged onto the ground and into septic tanks, storm drains, or wells.
5. Agrichemical mixing and loading facilities. Almost all agrichemicals must be diluted to field strength prior to application. Mixing and loading facilities have been identified as frequent sources of groundwater contamination; chemicals can spill or siphon into wells, water supplies, surface water, septic tanks, or storm drains.
6. Chemigation (application of chemicals via irrigation). Uses smaller amounts of chemicals over a given time and reduces potential for leaching, but system must be properly designed to prevent groundwater contamination, mainly caused by backsiphoning into the water supply.
7. Storage and disposal of agricultural solid wastes. Uncomposted animal wastes, empty pesticide containers, and plastic mulch can contaminate groundwater or air (if containers or mulch are burned).

Documentation: Dade County Department of Environmental Resources Management, Planning and Evaluation Section. 1990. Agricultural and agrichemical-related operations within the West Wellfield Interim Protection Area: II. Existing regulations and options to control potential pollution point sources. Report to the West Wellfield Policy Advisory Committee. July 30, 1990. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Summary of potential pollution nonpoint sources in the West Wellfield Protection Area. Nonpoint sources involve application of agrichemicals, defined as materials applied to enhance plant productivity

(fertilizers, soil amendments including composted sewage sludge and composted municipal solid waste) or to control pests (pesticides, including herbicides, rodenticides, fungicides, fumigants, etc.). Considered on pollution within interim protection boundary. West Wellfield planning process evaluates threats to groundwater quality from existing sources but also possible impacts of any allowable land use. Toxicity of agrichemicals can be either acute or chronic and can be caused by active ingredients, inert ingredients (sometimes more toxic than the active), breakdown products, and metabolites. Dithiocarbamate fungicides (maneb, zineb, mancozeb, etc.) are widely used in Dade Co. Although the parent compounds are relatively safe, the breakdown products, especially ethylenethiourea (ETU) are toxic to the thyroid and are mutagenic, carcinogenic, and teratogenic in experimental animals. Also, current drinking water standards to not account for interactive health effects of chemical combinations. The environmental fate of an agrichemical depend on the product's physiochemical properties (water solubility, soil adsorption, volatilization, persistence), hydrogeological factors (soil structure and topography, soil characteristics, aquifer characteristics, and meteorologic conditions), and management practices (rate, efficiency, timing, and method of application; application efficiency; and irrigation and cultivation practices).

In 1989, almost 4800 acres of row crops were grown in Dade Co., including 2660 acres of beans and 1350 acres of corn. Much of this acreage was within the projected 30-day travel boundary of the wellfield. Water conservation is occurring with a gradual shift from high-volume water guns to more efficient low-volume systems, including drip irrigation. A study by IFAS indicated that South Florida tomato growers often apply fertilizers at 2-3 times the recommended rate and that nitrogen application rates could be reduced substantially. Farmers have found it impossible to produce high-quality, profitable crops without relying on pesticides. Squash, corn, and tomatoes require a broader array and more frequent applications of pesticides than other row crops. 10 or more different insecticides are typically used on beans, corn, and tomatoes, with 20 separate applications estimated per crop of corn and 16 applications on tomatoes. Fungicides are applied at a similar frequency on corn and tomatoes. 7 different fungicides may typically be used on a crop of tomatoes. Up to 30 applications of fungicides and 25 applications of insecticides may be used on tomatoes per year. 2.3 million pounds of the pre-planting soil fumigants methyl bromide and chloropicrin were sold to Dade Co. farmers in 1985-86. These are applied to fields at rates of 250-350 lbs/acre, mainly for tomatoes and strawberries. Although usually applied without incident, emergency evacuations have arisen when a fumigant drifted into rural neighborhoods.

47 different pesticide active ingredients are reported to be used on row crops in Dade Co. (23 insecticide/miticides, 13 herbicides, 9 fungicides, 2 fumigants). The EPA has identified 17 of these ingredients as most likely to leach. The herbicide atrazine has been detected at low levels in wells in Dade Co. agricultural areas. Only one chlorinated hydrocarbon (endosulfan) is still used, but low levels of others (chlordane, dieldrin, and heptachlor) have been detected in local groundwater.

The WWIPA contains about 50 acres of fruit groves, mainly avocado, lime, and mango. Generally, heavier levels of nutrients are applied in groves than in row crops. Mangos are the most susceptible to fungal disease; the amount of fungicide applied on mangos (an estimated 24 applications per year) exceeds the quantity of all pesticides applied on avocados and limes combined. 4 of the 22 active ingredients used are identified as a concern to groundwater quality.

Approximately 2000 varieties of ornamental plants are grown in Dade Co. in wholesale and retail facilities that range from small backyard operations to large greenhouse complexes. Nurseries for foliage are the major concern because they use pesticides more intensively than do nurseries for woody ornamentals. In the WWIPA there are 68 foliage container nurseries and 2 field nurseries that cover a total of 210 acres. Several practices of foliage nurseries are potential pollution sources that may lead to leaching: 1) year-round cultivation schedule; 2) frequent, intensive application of fertilizers and pesticides; 3) high rate of irrigation; 4) use of backfilled trenches or other water drainage structures. Up to 50 applications per year may be made of fungicides and insecticides. 42 different pesticide ingredients are used, including 8 identified by EPA as a groundwater concern.

Several other types of operations in the WWIPA that use agrichemicals are potential sources of nonpoint pollution. These include aquaculture (25 producers and trans-shippers in Dade Co.), animal husbandry, aquatic weed control, right-of-way maintenance (in Dade Co. 4000 acres by state, 17000 acres by county), golf courses (total of 430 acres in the WWIPA), residential lawn maintenance (9,000 acres in the WWIPA), mosquito control.

Monitoring groundwater for agrichemical residues: Presence of elevated nitrate levels is clearest indication of agrichemicals; major component of fertilizers and component least attenuated in soil and groundwater. In actively farmed areas, nitrates can be 2 or 3 times higher than background levels and occasionally exceed drinking water standards. Pesticide detection in local studies has been sporadic because of variation in product use. Testing was limited by little relation to actual products that were used and by little testing for breakdown products. Golf courses impact groundwater more than do other urban landscaping activities. Several studies have concluded that agriculture is a major contributor to elevated levels of fertilizer components in groundwater, public drinking water supplies, and private wells in South Dade Co. Low levels of pesticides have also been detected in groundwater from the East Everglades agricultural area, in addition to high levels of paraquat in one sample and of chlorothalanil in another. Some of the highest values of agrichemicals were found in samples from open, uncased irrigation wells. A 3-year monitoring study found low levels of one or more chlorinated pesticides in 63% of groundwater samples. Although pesticide monitoring is infrequent, detectable levels of endrin, aldehyde, lindane, dieldrin, and clorothalonil have been found in 30% of agricultural sites sampled in the WWIPA. In a 1989 study, 84% of groundwater samples from agricultural areas of Dade Co. showed positive detections for the herbicide atrazine; found in open wells, private potable wells, and a USGS monitoring well. Farming impact on groundwater as well as canal water quality still evident in routine surveillance data collected by DERM in 1990. Highest values of nitrates in private wells are in predominately farmed areas. Elevated nitrate levels have been found in public drinking water facilities. Florida City and Homestead showed very high levels in 1977, but levels were substantially lower in 1989. Nitrate levels were much lower in central and north Dade urban areas, except at a wellfield next to a golf course in North Miami Beach and a wellfield in central Dade where farming was still prevalent in the mid-1970s. The Florida Keys Aqueduct Authority wellfield in South Dade has not shown elevated nitrate despite being near active row crop operations. A large tract of native pinelands surrounds the plant and covers most of the protection area, providing a zone of pristine recharge. Pesticides have generally been detected in public drinking water supplies.

Documentation: Dade County Department of Environmental Resources Management, Planning and Evaluation Section. 1991. Agricultural and agrichemical-related operations in wellfield protection areas: II. Introduction to potential non-point sources of water pollution. Draft Report to the West Wellfield Technical Advisory Committee. March 5, 1991. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida. [This report has been left as a draft because they never received comments from the Committee.]

Summary of agrichemical issues in West Wellfield Interim Protection Area: Identifies concerns about the adequacy of the county groundwater monitoring program and existing regulatory controls for assessing current conditions and protecting the municipal drinking water supply.

1. Groundwater monitoring program. Established in the WWIPA in February 1990; sampling has occurred bimonthly except for minor breaks. Parameters measured include major cations/anions, nutrients, trace metals, volatile organic compounds. Pesticide monitoring is included but is infrequent, may not be synchronized with use patterns, and does not include major breakdown products. Samples collected in Dade Co. by DERM and USGS have indicated nitrate levels that are evidence of groundwater degradation attributable to use of fertilizers. A potential also exists for pesticides to enter groundwater. Samples collected by DERM and SFWMD throughout Dade Co. have revealed positive, although infrequent and low-level, concentrations of pesticides such as chlorothalonil, atrazine, and endosulfan. Samples from the WWIPA detected low and infrequent concentrations of persistent chlorinated pesticides. The Dade Co.

Code classifies pesticides, fertilizers, and soil amendments as hazardous materials and prohibits their use by new commercial activities in the WWIPA. However farmers, homeowners, and already existing commercial activities, including 3 golf courses, are exempt. Characterization of local usage patterns for pesticides, fertilizers, and soil amendments thwarted by lack of adequate data, regulations on record-keeping, etc. Issues: Are locations of monitoring wells adequate? Is existing information on agrichemical use in the WWIPA adequate?

2. Fertilizer and soil amendment regulations. Besides vital nutrients and trace metals, materials can also contain impurities such as heavy metals. Nitrate levels of groundwater in farmed areas have indicated degradation. There is no central repository of data on local patterns of pesticide usage. The Florida Dept. of Agricult. and Consum. Serv. (FDACS) requires users of restricted-use pesticides to keep records of purchase and use, but these do not have to be submitted unless requested. Only 1 in 5 licensed applicators in each county are sampled annually by FDACS in a state-wide survey of restricted-use products. The majority of pesticides used in Dade Co. are non-restricted products for which there is no reporting mechanism. Also, the classification as "restricted-use" is based on acute toxicity due to exposure and does not consider potential for leaching to groundwater. No recordkeeping or reporting requirements exist for fertilizer and soil amendment use. Over 100,000 tons of fertilizer were used in Dade Co. in FY 1990-91. By DERM policy only domestic wastewater residuals (e.g., Milorganite) that have met the highest standards for heavy metal concentration and pathogen stabilization can be used in wellfield protection areas. A 1985-87 study by USGS in the South Dade agricultural area did not show any deterioration in groundwater quality because of leaching from sludge. Issues: Are IFAS crop recommendations for application adequate for minimizing leaching? Are existing regulations for domestic wastewater residuals and composted solid waste adequate?

3. Pesticide registration. FDACS review process can include a computer-generated ranking process and a 28-year model of movement through and past the root zone. These include only approximations assumed applicable for the entire state. Issues: Is current registration process adequate for unique characteristics of Dade Co. aquifer? What mechanisms are used to verify users follow label requirements? Will a Generic State Management Plan be specific enough to protect groundwater in WWIPA?

Documentation: Dade County Department of Environmental Resources Management, Planning and Evaluation Section. 1992. Issues regarding pesticide, fertilizer and soil amendment use within the West Wellfield Interim Protection Areas. Report to the West Wellfield Technical Advisory Committee. July 7, 1992. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Dade County Department of Environmental Resources Management, Water and Sewer Division.

Wellfield protection activities. There is no standard monitoring network around wellfields, but potential pollution sources of groundwater contamination are assessed. For example, based on modeling reflecting anticipated increases in wellfield pumping from the Florida Keys Aqueduct Authority wellfields, the designated wellfield protection area was expanded. Within this expanded area, three potential contamination sources existed: a hurricane debris stockpile site, a produce packing house, and a primate breeding facility. The USACOE analyzed extensive soil, groundwater and surface water samples from the debris site as part of required monitoring/remediation actions. Even though site cleanup was completed 5/93 and row crop farming had resumed on the site, DERM was requiring additional sampling as of 12/93. Because of chemical residues that can be present in wash water and sludge wastes, the packing facility is constructing a collection and recycling system. The primate breeding operation was to be connected to the sewer system by 2/94 to replace septic tanks being used for animal and human waste.

Documentation:
Harvey Kottke, Water Supply Section, Water and Sewer Division, pers. comm.

Yoder, D. 1993. Letter to Paul Mitchell, Director of Engineering, Florida Keys Aqueduct Authority, plus enclosures including wellfield protection activity summaries. December 3, 1993. Metropolitan Dade County Department of Environmental Resources Management, Water and Sewer Division, Miami, Florida.

U.S. Geological Survey, Water Resources Division, Tallahassee, Florida.

Reconnaissance of agrichemicals in water from open irrigation wells. In 1993 the USGS sampled 14 wells, including 8 mix-load wells, in South Dade Co. in August when several sites were fallow and again in December when fertilizer and pesticide applications are normally greatest. In the August sampling, samples from 2 wells showed nitrate concentrations greater than the FDEP maximum contaminant level of 10 mg/L for primary drinking water standards. The level at one of the sites was 1600 mg/L. In December, samples from 3 other wells had nitrate levels above the MCL; one was above 1000 mg/L. Pesticide analyses showed several compounds above analytical detection levels; endosulfan compounds were among the most frequent. Of the 11 different chemicals detected, only 3 - atrazine, heptachlor expoxide, and toluene - have MCLs, and levels of these were less than their MCLS.

Documentation: McKenzie, D. 1994. Letter to R. DeHan, Florida Department of Environmental Protection, plus enclosures summarizing results of reconnaissance of agrichemicals in water from open irrigation wells in Dade County, Florida. April 18, 1994. Water Resources Division, U.S. Geological Survey, Tallahassee, Florida.

South Florida Water Management District.

South Dade agricultural pilot study. 22 wells were sampled to establish background value during months of no farming for parameters such as nutrients, major ions, metals, volatile organics, and pesticides. Results suggested that agriculture has had localized impact on the water quality of the Biscayne aquifer. Pesticides once used in the agricultural area were persistent in the groundwater. Aldrin, dieldrin, and DDT were present in excess of potable surface water standards. Elevated metal concentrations (e.g., manganese, copper, iron, zinc) were found in 2 wells.

Documentation: Anderson, S.D. 1986. South Dade agricultural pilot study. Technical Memorandum. Water Quality, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

East Everglades ground water quality monitoring study. A 2-year groundwater monitoring study was initiated to determine the potential adverse water quality impacts to the Biscayne aquifer resulting from agricultural practices in South Dade. 16 groundwater, 4 surface water stations, and 12 soil stations were sampled in the 1985-86 growing season. The stations were representative of both active and nonactive agricultural practices. The data indicated elevated concentrations of select inorganic and organic parameters representative of agricultural activity. Concentrations of inorganic chemical parameters were elevated in active agricultural areas compared to nonactive areas, likely reflecting use of fertilizers; differences were significant for conductance, total dissolved solids, potassium, sulphate, and chloride. 6 organic pesticides (aldicarb, paraquat, atrazine, metribuzin, chlorothalonil, and permethrin) were found at 14 groundwater and surface water stations. Overall aquifer water quality in the study area, however, met established standards. Current farming practices, combined with dilution during the wet season, appear to minimize impacts on the aquifer.

Documentation: Anderson, S.D., and J.E. Shaw. 1991. East Everglades ground water quality monitoring study, 1985-1986. Technical Memorandum. Hydrogeology Division, Research and Evaluation Department, South Florida Water Management District, West Palm Beach, Florida.

U.S. Environmental Protection Agency.

Munisport Landfill studies. Investigations at this North Dade Co. landfill in 1988 showed that landfill leachate was moving south east towards a mangrove preserve on Biscayne Bay. Bioassays of this material showed it to be acutely toxic. Another study was conducted in 1989 to evaluate emergence of leachate in surface waters of the mangrove preserve, assess potential toxic effects of its mixing with surface waters, and assess the nutrient potential of it mixing with waters of the preserve and being discharged to the bay. Results established that leachate-contaminated groundwater from the landfill migrated to the preserve and mixed with tidal surface waters of the bay. The leachate contained extremely elevated concentrations of ammonia; the levels of unionized ammonia, the most toxic form, exceeded those established for protecting marine life and water quality.

Documentation:

U.S. Environmental Protection Agency. 1990a. EPA selects remedy to abate environmental threat at Munisport Superfund site, Miami, Florida. News release. United States Environmental Protection Agency, Region 4, Atlanta, Georgia.

U.S. Environmental Protection Agency. 1990b. Munisport Landfill public meeting at Florida International University re: National Priorities List site. March 29, 1990. Transcript.

U.S. Environmental Protection Agency. 1994b. Superfund fact sheet, explanation of significant differences, Munisport Landfill Superfund Site, North Miami, Florida. United States Environmental Protection Agency, Region 4, South Superfund Remedial Branch, Atlanta, Georgia.

U.S. Environmental Protection Agency. 1994c. Superfund update, Munisport Landfill. Superfund Volume 1, No. 4. United States Environmental Protection Agency, Region 4, Munisport Project, Oak Ridge, Tennessee.

U.S. Fish and Wildlife Service. 1980. 1:250,000-scale map of Atlantic Coast ecological inventory, Miami, Florida. 25080-A1-E1-250. U.S. Geological Survey, Reston, Virginia.

REGION

South Florida Water Management District.

Ambient Ground Water Quality Network. Water quality sampling began in 1984 in an extensive network of monitor wells in 15 of the District's 16 counties (all but Monroe). Eastern Palm Beach, Broward, and Dade counties are included in the network. Sampling in Dade and Broward is subcontracted by the District to Dade DERM and Broward EQCB. Samples are analyzed for physical parameters, nutrients, major ions, trace metals, and purgeable organics (halocarbons and aromatics).

Documentation: Herr, J.W., and J.E. Shaw. 1989. South Florida Water Management District ambient ground water quality. Technical Publication 89-1. Water Quality Division, Resource Planning Department, Central and Southern Florida Flood Control District, West Palm Beach, Florida.

Production zones of wellfields. Maps were prepared to identify well production zones and show the three-dimensional location of public water wellfields in the District. Data were from water use permit applications and from responses to inventory questionnaires. Results indicated that many counties are dependent on relatively shallow ground water supplies less than 150 ft from the surface. This is particularly evident in the Lower East coast, where the surficial aquifer is the major supplier of potable water. Dade Co. pumps 100% and Broward pumps over 90% of their permitted capacity from less than 150 ft. and often much less.

Documentation: Alvarez, J.A., and D.D. Bacon. 1988. Production zones of major public water supply wellfields for the counties in the South Florida Water Management District. Technical Publication 88-4 and Appendix II. Water Quality Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

U.S. Geological Survey, Water Resources Division.

Water resources data collection. During each water year (October-September), the USGS obtains a large amount of data on Florida water resources. The data include records of stage, discharge, groundwater levels, and water quality of streams; and stage, contents, and water quality of lakes and groundwater wells. Throughout Subregion 9, water level is monitored in almost 140 wells either by digital water-level recorders or satellite data collection platforms. Specific conductance and concentration of dissolved chloride are measured.

Documentation:
Haire, W.J., and C. Lietz. 1993. Water resources data - Florida, 1992. Volume 2B: South Florida ground water. Water-Data Report FL-92-2B. U.S. Geological Survey, Miami, Florida.

STORMWATER

PALM BEACH COUNTY

South Florida Water Management District.

Evaluation of floodwater management in the C-51 basin. An evaluation was conducted to examine alternatives for improving water management conditions in western Palm Beach Co. to protect existing development from flood damages, determine the impacts of improved management on flood conditions, and determine the impacts of backpumping on environmental resources. One potential problem with backpumping is the use of pesticides in the basin and also the practice of using sewage sludge on pastures and citrus groves.

Documentation: South Florida Water Management District. 1984b. Water management planning for the western C-51 Basin. DRE 178. Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Investigations of surface water management systems. Studies have been conducted on the efficiency of systems in residential and commercial developments. A study at the Boynton Beach Mall investigated water quality and quantity interactions associated with a wet detention system of three interconnected ponds that discharged into a local drainage canal. The system was found to be an effective means of reducing stormwater nutrient mass loads entering receiving waters.

Documentation:
Holler, J.D. 1989. Water quality efficiency of an urban commercial wet detention stormwater management system at the Boynton Beach Mall in south Palm Beach County, Florida. Florida Scientist 52:48-57.

Timbercreek Subdivision stormwater monitoring. This single-family residential development in Boca Raton has a drainage system of grassed swales, catch basins, storm sewers, and an interconnected system of detention lakes. Data were collected to assess methodologies used to compute ground storage and runoff volumes, structure performance compared to theoretical values, detention lake performance, and water quality improvement. Levels of seepage into the surface lakes resulting from storm-induced elevated groundwater levels were higher than expected. Groundwater-surface water interactions require additional analysis. The swale-lake system provides significant removal of suspended solids and dissolved nutrients from runoff. It also provided excellent attenuation of the runoff hydrograph.

Documentation:
Cullum, M.G. 1984. Evaluation of the water management system at a single family residential site: water quality analysis for selected storm events at Timbercreek subdivision in Boca Raton, Florida. Technical Publication 84-11, Volume II. Water Chemistry Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.
Gregg, J.R. 1984. Evaluation of the water management system at a single family residential site, hydrology and hydraulics of Timbercreek subdivision in Boca Raton, Florida. Technical Publication 84-11, Volume I. Water Resources Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

Modeling of rainfall-runoff. A system integrating a hydrologic model and a hydraulic routing model was developed that addresses the flat topography and complex canal networks of South Florida. The models

were applied to the Hillsboro Canal basin in Palm Beach and Broward counties, as part of an ongoing USCOE flood control study in the basin.

Documentation: Obeysekera, J., R.L. Barkau, and C. de Rojas. 1993. Linking hydrologic and hydraulic routing models in low relief basins of South Florida. DOR Paper 121. South Florida Water Management District, West Palm Beach, Florida.

U.S. Army Corps of Engineers.

Evaluation of flood management for west C-51 basin. The principal alternative evaluated was the construction of a detention area east of the northeast corner of WCA-1. Water would be pumped from C-51 into the detention area, stored for a short period of time, and then released back into C-51 later when the canal system could deal with the water. The plan would tend to moderate extreme salinity fluctuations in Lake Worth by reducing peak discharges of fresh water. Two other alternatives (building a detention area inside WCA-1 and discharging stormwater directly into WCA-1) would have unacceptable adverse environmental impacts. The alternative of no action is also unacceptable because of extensive damage that will occur.

Documentation: U.S. Army Corps of Engineers. 1992. Part V, supplement 54, detail design memorandum addendum 2 (revised), Canal 51 - west end, control structures 155A, 360, pumping station 319 and levee 85. Central and Southern Florida Project, U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, Florida.

BROWARD COUNTY

Broward County Department of Natural Resource Protection.

Stormwater monitoring program. Program has been implemented to fulfill requirements of EPA's NPDES (National Pollutants Discharge Elimination System). A stormwater program is also proposed to monitor environmental degradation associated with industrial activities in and around the Fort Lauderdale International Airport.

Documentation: Frazel, D. 1994. Letter to J. Browder. March 22, 1994. Broward County Department of Natural Resource Protection, Water Resources Division, Fort Lauderdale, Florida.

U.S. Geological Survey, in cooperation with Broward Co. Transportion Dept., Environmental Quality Control Board, and Water Management Div.; and Florida Dept. of Transportion and Dept. of Environmental Regulation.

Stormwater runoff quality from three land-use areas. Stormwater studies were done during 1974-78 on a single-family residential site, a commercial site, and a highway site. Synchronized data were collected for rainfall, stormwater discharge, water quality, and bulk precipitation quality. Analysis showed that most runoff was from impervious areas hydraulically connected to drain inlets. The residential area yielded the largest loads of nitrogen, phosphorus, and dissolved solids. The commercial area yielded the largest loads of lead, zinc, and chemical oxygen demand.

Documentation:
Mattraw, H.C., J. Hardee, and R.A. Miller. 1978. Urban stormwater data for a residential area, Pompano Beach, Florida. Open-File Report 78-324. U.S. Geological Survey, Tallahassee, Florida.

Mattraw, H.C., and R.A. Miller. 1981. Stormwater quality processes for three land-use areas in Broward County, Florida. Water-Resources Investigations Report 81-23. U.S. Geological Survey, Tallahassee, Florida.
Miller, R.A., and H.C. Mattraw, Jr. 1982. Storm water runoff quality from three land-use areas in South Florida. Water Resources Bulletin 18(3):513-519.

U.S. Geological Survey, in cooperation with Broward Co. Water Resources Management Div.

Effects of highway runoff on Biscayne Aquifer. Two sites adjacent to heavily traveled highways were studied during 12 storms in 1983 to determine if stormwater percolating through unsaturated sand underlying vegetated swales may affect the quality of water in the surficial Biscayne Aquifer. There was significant near-surface accumulation of trace metals (iron, lead, zinc), but chemical attenuation of the percolate with depth resulted in no obvious water-quality effects on the aquifer.

Documentation: Howie, B., and B.G. Waller. 1986. Chemical effects of highway runoff on the surficial aquifer, Broward County, Florida. Water-Resources Investigations Report 86-4200. U.S. Geological Survey, Tallahassee, Florida.

DADE COUNTY

Dade County Department of Environmental Resources Management, Water Management Division, Stormwater Monitoring and Evaluation Section.

Stormwater monitoring program. Under EPA's NPDES (National Pollutants Discharge Elimination System), all cities over 100,000 are required to monitor stormwater for a required set of 12 pollutants (BOD, COD, TSS, TDS, TKN, nitrates and nitrites, total PO_4, ortho PO_4, Cd, Cu Pb, Zn). A survey of all outfalls (Phase I) began around 1990. Phase II began in July 1992 with 12 sites in Dade Co. being sampled during 3 rain events per year. Each site is representative of a certain land use or a combination of uses. These include transportation, sales and services, multi-family, single-family, golf course, shopping center, and industrial. Results are compared to those obtained through EPA's National Urban Runoff Program.

Documentation:
Rolando Rodriguez (Biologist II), pers. comm.
Dorian Valdes (Section Chief), pers. comm.
Rodriguez, R. 1994. Letter with tables to Carole Goodyear dated May 17, 1994. Metropolitan Dade County Department of Environmental Resources Management, Water Management Division, Miami, Florida.

South Florida Water Management District.

Surface Water Improvement and Management (SWIM) Program for Biscayne Bay. This updated 1994 planning document replaces the 1988 SWIM plan. It reviews progress on the original recommendations and recommends revised goals, objectives and strategies for the next 3 years. Since 1988, SFWMD has participated in 50 major projects through the SWIM Program, many of these in cooperation with Dade Co. DERM. These projects included research, monitoring, restoration, and education. One of the program's important achievements was to assist DERM to expand the water quality monitoring program in the bay and establish a longterm database for identification of problems. Stormwater runoff is a major water quality concern in Biscayne Bay; more than 50% of the program funding has been on pollution problems created by urban stormwater systems. Urban land uses, including

residential, commercial, industrial, institutional, transportation, and landfill areas, are considered to be the source of most water quality problems in the bay. A wide variety of contaminants and pollutants may originate from these sources, many not detectable through routine monitoring programs. Stormwater from agricultural areas may also contain several types of pollutants. Several proposed projects of the SWIM Program deal with stormwater are listed in the tables in the section on water quality, taken from the planning document.

Documentation: Alleman, R., D. Black, S. DuToit, S. Formati, C. Gove, and L. Gulick. 1994. An update of the Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. Draft planning document, technical supporting document, and appendices. Lower East Coast Planning Division, South Florida Water Management District, West Palm Beach, Florida.

Dade County Department of Solid Waste Management (Conducts wetlands restoration for stormwater retention).

Stormwater retention pond at the Dade County Resources Recovery Facility. A 14-acre retention pond is being built at this facility in northwest Miami, as required by COE permit to compensate for loss of 26 acres of melaleuca-dominated wetlands associated with closure of an existing ash landfill and expansion of a new ash landfill. The project will permanently convert the area to a primarily herbaceous wetland with diverse native species. The pond will include 8 acres of littoral shelf. The project is designed to be flooded at the surface for at least 9 months of the year to limit the establishment of melaleuca. In 6/94, the planting of the project was about 60% complete.

Stormwater retention basin at the South Dade Landfill. The plan for closure of the landfill includes collection of all runoff coming off the capped landfill cells in perimeter swales feeding into a 54-acre wetland retention basin. Stormwater will percolate into the groundwater, and no offsite discharge will be allowed. The basin will be surrounded by a 12-ft wide, 10.5-ft high dike and will be divided into 3 zones by a berm system that will control water elevations in the zones. The wetland hydroperiod is being studied to determine optimum elevation of the spillways to ensure survival of native wetland plants. The basin will include freshwater marsh and brackish water habitat, and the berms will be planted with tropical hammock species. All exotic plants will be eradicated. Fish populations and recruitment will be studied in the 3 zones. In 6/94, the construction phase was ready for competitive bidding.

Documentation: Danhausen, K. 1994. Letter to C. Goodyear with summary of wetland restoration projects. Metro Dade Department of Solid Waste Management, Miami Florida.

South Florida Limestone Mining Coalition.

Freshwater Lake Belt Plan. More than half the construction-grade rock used in the entire state of Florida is supplied by Dade Co. The products include cement and asphalt, limerock road base, and environmental products such as rip-rap for shoreline erosion control and materials for septic tank drainfields, stormwater seepage trenches, and treatment plant filters. Most mining is done in a narrow strip of 41,000 acres of degraded wetlands (drained, infested by melaleuca) between the urban area and the WCAs. Each year mining transforms 300-400 acres of this land into deep lakes. A 1983 EIS by the USACOE determined rockmining in degraded wetlands was the preferred alternative. In 1984, the area was given an exemption from wetlands jurisdiction by the Florida legislature; this exemption expires in 1994. In 1990 a consortium of 6 Dade Co. rock mining companies began a 2-year study to compile information and recommend an approach to protect the area's environment and water supply, as well as to provide a continuing supply of aggregate. The Northwest Dade County Freshwater Lake Plan proposes a system of large lakes in the mining area, including 20,000 areas of lakes added to an existing 4,000 acres and 17,000 acres as constructed littoral wetlands, recreation areas, and existing wellfields. An adjoining 13,000-acre area that is relatively pristine (74% prairie) would be preserved and maintained in natural

condition. The plan proposes that by mining the area to form lakes, water storage is increased, the lakes could be used to hold backpumped stormwater, and seepage under WCA levees may be reduced. The system would form a 6-mile buffer strip between urban areas and WCAs, stopping urban sprawl from encroaching on the Dade Co. Northwest Wellfield, which lies in the center of the area. The existing lakes already have a substantial bass population; the proposed area could be developed into a prime recreational amenity. The Governor signed a bill creating the Northwest Dade County Lake Plan Implementing Committee in 1992.

Documentation:
Larsen and Associates. 1992. South Florida Limestone Mining Coalition Year 2050 Freshwater Lake Belt Plan. Larsen and Associates, Miami, Florida.

Dade County Department of Environmental Resources Management.

Lake belt environmental studies. DERM was invited by the USACOE to cosponsor the EIS process and to coordinate development of a scope of work, obtain cost estimates, and solicit qualified professionals to perform necessary ecological studies associated with the Freshwater Lake Belt Plan. A scope of services was prepared to evaluate the existing function and quality of freshwater wetlands within the Lake Belt study area. A comprehensive study of existing lakes and littoral areas will be done (Nova Univ.), existing vegetation and soil conditions will be mapped (EAS Engineering), and quantitative data will be collected on wildlife populations using the area (Everglades Research Group). The data will be used to analyze future environmental conditions under various scenarios involving excavation of deepwater lakes and protection and enhancement of adjacent wetlands. The 2-year studies were to begin in 12/93. Costs were to be shared by South Florida Limestone Mining Coalition (50%), SFWMD (25%), USACOE (12.5%), and Water & Sewer Authority Dept. (12.5%).

Documentation:
Yoder, D. 1993. Status report on environmental studies, Lake Belt contract. Summary prepared for J. Browder, 11/8/93. Metropolitan Dade County Department of Environmental Resources Management, Director's Office, Miami, Florida.

REGION

South Florida Water Management District.

Stormwater research. Because of increasing concern over stormwater runoff as a significant pollution source, the SFWMD took an active role in stormwater research. Multiple stormwater management systems have been evaluated, and many modeling efforts have been conducted for nonpoint source pollution occurrence and control.

Documentation: Whalen, P.J., and M.G. Cullum. 1988. An assessment of urban land use/stormwater runoff quality relationships and treatment efficiencies of selected stormwater management systems. Technical Publication 88-9. Water Quality Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

U.S. Environmental Protection Agency.

National Pollutants Discharge Elimination System (NPDES).
[waiting for information]

SURFACE WATER/SEDIMENT QUALITY

PALM BEACH COUNTY

South Florida Water Management District.

Pesticide residue monitoring. During 1976-80, water and/or sediment at various locations were sampled in cooperation with USGS. The Hillsboro Canal was a periodic sampling site. At the time of sampling, the stations were in an agricultural area and showed high concentrations of DDT, DDE, DDD, chlordane, and dieldrin.

Documentation:
Pfeuffer, R.J. 1985. Pesticide residue monitoring in sediment and surface water bodies within the South Florida Water Management District. Technical Publication 85-2. Water Chemistry Division, Resource Planning Department, Central and Southern Florida Water Management District, West Palm Beach, Florida.

BROWARD COUNTY

Broward County Department of Natural Resource Protection.

New River Study. This is the first in a series of basin assessments intended for Broward County. It was a baseline study with the objective to assess the nature and extent of water quality issues in the New River. Sampling was conducted during June 1991 and January 1993; more than 3,000 samples were collected to measure 35 parameters. 13 stations were sampled from 6/91-12/92. 10 additional stations were added in 3/92 and sampled until 1/93. The New River is one of the few naturally occurring water bodies in Broward County, almost all surface freshwater flow is regulated. The river is divided into 3 basins: North Fork (relatively stagnant, little tidal or freshwater input, high bacteria and nutrients, low dissolved oxygen); Las Olas Isles (high bacteria levels associated with inhabited moored vessels), and South Fork to Intracoastal (significant flushing, chemistry typical of groundwater). The study scope included: on-site visual survey to identify potential point source impacts; monthly sampling for general water quality parameters; bi-monthly sampling for water column metals, algae, and phytoplankton; at least 2 composite samples during a storm event at 2 outfalls for water quality parameters, metals, organics, and pesticides; annual sampling of 13 stations for pesticides in water column; one-time sediment sampling at marine maintenance facilities; 18 samplings of sludge blanket in North Fork for metals, nutrients, organics, benthos, and biotoxicity; one-time 24-hr. profile in North Fork for temperature, dissolved oxygen, salinity, conductivity, and Ph; and aerial survey of number of moored boats in Las Olas Isles area. DNRP is preparing a New River Restoration Plan that will include methods of improving water quality and biological function. DNRP is also conducting a bioaccumulation study designed to evaluate potential health effects of eating fish and crabs caught in the North Fork; this was to be completed in spring 1994.

Documentation: Broward County Department of Natural Resource Protection. 1993. New River study: final report. Technical Report Series TR:93-06. Broward County Department of Natural Resource Protection, Fort Lauderdale, Florida.

Surface water quality monitoring program. The objective is to characterize the chemical, biological, and physical composition of Broward Co.'s water bodies and drainage basins so that any necessary remedial measures can be focused toward improving water quality and subsequently ecological health. The Environmental Monitoring Div. samples 46 stations quarterly. Parameters include: fecal and total coliform,

conductivity, pH, temperature, total organic carbon, turbidity, dissolved oxygen, salinity, nitrate and nitrite, ammonia, total Kjeldahl nitrogen, and total phosphorous. The program was started in the early 1970s; data beginning in 1988 are in computerized format. This program needs to be expanded because the county is now the manager of Port Everglades.

Documentation: Frazel, D. 1994. Letter to J. Browder. March 22, 1994. Broward County Department of Natural Resource Protection, Water Resources Division, Fort Lauderdale, Florida.

Sediment toxicity. A survey to determine the biotoxicity of sediments in the county's waterways was to be completed by 6/94. A study is proposed to assess the abilities of marine organisms to assimilate and concentrate contaminants deposited in sediments during marine industrial activities.

Documentation: Frazel, D. 1994. Letter to J. Browder. March 22, 1994. Broward County Department of Natural Resource Protection, Water Resources Division, Fort Lauderdale, Florida.

Bacteria monitoring. Monitoring of bacterial levels in the Las Olas Isles area is continuing under a cooperative agreement with the City of Fort Lauderdale.

Documentation: Frazel, D. 1994. Letter to J. Browder. March 22, 1994. Broward County Department of Natural Resource Protection, Water Resources Division, Fort Lauderdale, Florida.

Florida Department of Environmental Protection.

Pesticide monitoring in surface water. Broward was one of 8 counties sampled from 1991-1993.

Documentation: Shahane, A.N. 1994. Pesticide detections in surface waters in Florida. pp. 408-416 *in* A.R. Dutton, editor. Toxic substances and the hydrologic sciences. American Institute of Hydrology, Minneapolis, Minnesota.

South Florida Water Management District.

Pesticide residue monitoring. During 1976-80, water and/or sediment at various locations were sampled in cooperation with USGS. The North New River was a periodic sampling site.

Documentation: Pfeuffer, R.J. 1985. Pesticide residue monitoring in sediment and surface water bodies within the South Florida Water Management District. Technical Publication 85-2. Water Chemistry Division, Resource Planning Department, Central and Southern Florida Water Management District, West Palm Beach, Florida.

North New River backpumping impact study. Water quality data was collected in 1982-83 before construction and during discharge to determine localized impacts of backpumped water from the North New River Canal into WCA-3A. Water and sediment were analyzed for nutrients, routine physical/chemical parameters, trace metals, chlorinated hydrocarbon and organophosphorus pesticides, herbicides, and PCBs. A contamination problem was not demonstrated.

Documentation:
Pfeuffer, R.J. 1985. Pesticide residue monitoring in sediment and surface water bodies within the South Florida Water Management District. Technical Publication 85-2. Water Chemistry Division, Resource Planning Department, Central and Southern Florida Water Management District, West Palm Beach, Florida.

South Florida Water Management District. 1984a. North New River backpumping water quality impact study report #1, preconstruction and initial operation. Technical Memorandum. Water Chemistry Division, Resource Planning Department, South Florida Water Management District, West Palm Beach, Florida.

DADE COUNTY

South Florida Water Management District.

Surface Water Improvement and Management (SWIM) Program for Biscayne Bay. This updated 1994 planning document replaces the 1988 SWIM plan. It reviews progress on the original recommendations and recommends revised goals, objectives and strategies for the next 3 years. Since 1988, SFWMD has participated in 50 major projects through the SWIM Program, many of these in cooperation with Dade Co. DERM. These projects included research, monitoring, restoration, and education. One of the program's important achievements was to assist DERM to expand the water quality monitoring program in the bay and establish a longterm database for identification of problems. Preliminary data analyses show that water quality has improved in recent years. Of 150 statistically significant trends, 78% showed improvement. Turbidity, dissolved oxygen, and coliform bacteria showed the most improvement. Ammonia and nitrate/nitrite were notable in the degradation category. Stations in canals near Black Point (landfill site) and the Miami River showed the greatest number of undesirable trends. Sediments in some locations exceed the state recommended levels of mercury, lead, zinc, copper, cadmium, PCBs, and chromium. Stormwater runoff is a major water quality concern in Biscayne Bay; more than 50% of the program funding has been on pollution problems created by urban stormwater systems. Tributyltin concentrations are of concern, and a ban on the use of all marine coatings containing the compound should be considered within the study area. The FDEP has recently endorsed the concept of establishing Pollution Load Reduction Goals for Florida water bodies. This is a concern in Biscayne Bay because it appears that excessive amounts of damaging substances are entering the system, and there is no pollutant entering Biscayne Bay for which needed information is completely known.

Documentation: Alleman, R., D. Black, S. DuToit, S. Formati, C. Gove, and L. Gulick. 1994. An update of the Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. Draft planning document, technical supporting document, and appendices. Lower East Coast Planning Division, South Florida Water Management District, West Palm Beach, Florida.

Pesticide residue monitoring. During 1976-80, water and/or sediment at various locations were sampled in cooperation with USGS. The Miami Canal was a periodic sampling site. The highest value of PCBs in the project was isolated from sediments in the canal in Hialeah.

Documentation:
Pfeuffer, R.J. 1985. Pesticide residue monitoring in sediment and surface water bodies within the South Florida Water Management District. Technical Publication 85-2. Water Chemistry Division, Resource Planning Department, Central and Southern Florida Water Management District, West Palm Beach, Florida.

Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Planning and Evaluation Section (Monitoring program establishes baseline data and assesses impacts of land use on water quality).

Ambient surface water canal monitoring. Quarterly water samples at 50 stations in tributaries and canals throughout Dade Co. for physical parameters (Ph, conductivity, nutrients, major anions, minerals,

inorganics, trace metals, organics, selected pesticides, and phenols) and occasional sediment sampling. The General Canal Program includes 50 stations and is to be revamped this year to coordinate with stormwater utility and bay monitoring. The Intensive Canal Program has collected extensive physical and chemical data on one individual canal each year since 1980 to determine whether agricultural land use or practices are contributing to the degradation of waters in Dade Co. Surveys have shown that surface waters have not been degraded below the limits of Class III standards. Testing is not comprehensive for pesticides.

Documentation: Ignacio, C. 1994. Letter with tables to C. Goodyear dated February 22, 1994. Metropolitan Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Miami, Florida.

Biscayne Bay Restoration and Enhancement Program. Initiated in 1979 to maintain and improve the value of the Bay system, this program is funded by state and local environmental trust funds and coordinated by DERM. The initial focus was monitoring and study of bay and tributaries and habitat and public access improvement. Routine water quality monitoring began in 1979 to identify typical or average conditions, large-scale geographic patterns, and changes in general water quality over extended time. Basic parameters (including physical characteristics, turbidity, inorganic nutrients, coliform bacteria, selected trace metals, and oxygen concentrations) were measured monthly or bimonthly at about 40 stations through the system, including several stations near the mouth of the Miami River. In 1984, emphasis on Miami River increased and 6 stations were added in the main river channel. In 1987, in connection with the SWIM Program, another 9 stations were added upstream of the salinity control structures and in Tamiami Canal and Wagner Creek. In 1988, the first stormwater outfall improvement project was completed in connection with the program.

Documentation: Dade County Department of Environmental Resources Management, Natural Resources Division. 1993. Miami River water quality plan. A report submitted to: The Miami River Water quality Commission, and Appendices B through H. Metro Dade DERM Technical Report 93-3. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Biscayne Bay Routine Surface Water Quality Monitoring Program. The objectives of the program are maintenance and improvement of water quality. The BBSWQMP has monitored surface water quality in Dumfoundling Bay, Biscayne Bay, and Card Sound monthly since 1979. Sampling was initiated in the Miami River in 1984 and in most of the other Bay tributaries in 1988. Stations in Barnes Sound were added in 1989. The primary and secondary canals, waterways and bays in Dade Co. are classified as Class III Waters by the state, with recognized uses as fish and wildlife propagation, recreation, and navigation. Portions of the Biscayne Bay system are within Biscayne NP, Everglades NP, and Biscayne Bay Aquatic Preserve and are classed as Outstanding Florida Waters. Permanent water degradation of any degree is not permitted.

The program conducts long-term routine systematic sampling of established stations, augmented with data collection from short-term investigative studies of incidents of pollution or specific projects that may contribute to reduced WQ. The scope has expanded from monitoring 15 parameters at 48 stations in 1979 to measuring 20 parameters at 90 stations in 1991. Water quality in the bays did not change markedly from 1987-91. Overall water quality in Biscayne Bay was acceptable, although geographic patterns exist. Water quality in North Bay is generally inferior to Central and South Bay due to recognized impact of canal and river discharges, habitat destruction, development of surrounding uplands, and less tidal exchange. Inorganic nutrients and phytoplankton levels are elevated in North Bay and at canal mouths. Parameters with higher than historical levels were coliform bacteria and ammonia nitrogen in select tributaries. Sewage contamination is the most frequently documented water quality problem, with coliform levels in the Miami River and other tributaries consistently violating WQ standards by several orders of magnitude. Widespread contamination is caused primarily by chronic leakage of sanitary sewage into storm drains; this

will be reduced with replacement of the aging sanitary sewage and stormwater collection infrastructure. Acute contamination is caused by emergency overflows during heavy rainfall or mechanical failures. Another major pollution source is point and non-point stormwater runoff. Poor WQ in Biscayne Bay caused by high bacteria, nutrient, or trace metal concentrations or low DO, however, is isolated and infrequent, and WQ consistently meets EPA, state, and county standards. There is still a threat, however, from point and non-point sources of contamination in heavily developed areas of Biscayne Bay. Stations with elevated ammonia nitrogen levels were at the mouths of two creeks downstream from major landfill sites. There is evidence that ammonia concentrations have been increasing over a period of years in these areas, and prolonged elevated levels are certainly affecting the ecosystem. Data show an overall average 24% decrease in water clarity during 1988-91 in Biscayne Bay.

Documentation:
Dade County Department of Environmental Resources Management. Undated. A data summary of the 1987-1991 Biscayne Bay and tributaries surface water quality monitoring program. Draft. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.
Dade County Department of Environmental Resources Management. Undated. The Biscayne Bay surface water quality monitoring program (BBSWQMP): Recommendations based on the July 1991 to June 1992 data. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Pesticide monitoring. Sampling by DERM in 1981-90 detected pesticides in Dade Co. canals, creeks and Biscayne Bay that included endosulfan I; heptachlor; P,P'-DDD; P,P'-DDE; P,P'-DDT; perthane; trifluralin; alpha-BHC; 2,3-D; aldrin; dieldrin; and endrin.

Documentation: Shahane, A.N. 1994. Pesticide detections in surface waters in Florida. pp. 408-416 *in* A.R. Dutton, editor. Toxic substances and the hydrologic sciences. American Institute of Hydrology, Minneapolis, Minnesota.

Biomonitoring at Black Point. Biomonitoring in Black Creek to determine the toxicity of the water in relation to nearby landfill. Ends 3/94.

Documentation: Ignacio, C. 1994. Letter with tables to C. Goodyear dated February 22, 1994. Metropolitan Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Miami, Florida.

Sediment quality at Black Point.

Documentation: Ignacio, C. 1994. Letter with tables to C. Goodyear dated February 22, 1994. Metropolitan Dade County Department of Environmental Resources Management, Environmental Monitoring Division, Miami, Florida.

National Marine Fisheries Service, Southeast Fisheries Science Center.

Pesticide monitoring in Florida Bay and agricultural watershed. In November 1993, 34 stations were sampled in a preliminary study to measure pesticide levels in surface water of Florida Bay and an adjacent inland, agricultural watershed. 18 stations were in the bay, 10 were at the land-sea interface, and 6 were in the C-111 canal system. 3 of the stations were also sampled for sediment pesticide levels. Quantifiable pesticide concentrations were found at 4 of the 6 canal stations and at 1 of the bay stations. The insecticide endosulfan (measured as its degradation product endosulfan sulfate) was the only pesticide measured at concentrations greater than detection limits. Preliminary screening also indicated presence of triazine herbicides at 7 stations, but no detectable levels were found. The endosulfan levels ranged from 0.002-0.170 μg/L, well above the Florida water quality criterion of 0.001 μg/L. The highest levels were found

in the C-111 canal at Highway #9336, near the entrance to Everglades National Park. Endosulfan is a supertoxic organochlorine insecticide. The increased flow of agricultural nonpoint source runoff into the Everglades and Florida Bay must be considered in plans to increase freshwater flow to the Everglades.

Documentation: Scott, G.I., M.H. Fulton, J.W. Daugomah, E.D. Strozier, P.B. Key, P.L. Pennington, B.C. Thompson, E.F. Wirth, and G. Thayer. 1994. Monitoring of pesticides in surface waters of Florida Bay and adjacent agricultural watersheds: implications for future management of freshwater inputs into Florida Bay. Charleston Laboratory, Southeast Fisheries Science Center, National Marine Fisheries Service, Charleston, South Carolina.

Survey of fish deformities in Biscayne Bay. Between 11/89 and 6/90 about 43,000 fish were caught during normal operation of a small-boat commercial fisherman in north Biscayne Bay and scanned for abnormalities. Stunted or missing dorsal spines or rays, sometimes accompanied by a depression in the dorsal profile, were found in 10 species in 6 families. Scale disorientation was found in 6 species. Pugheadedness, jaw deformities, and other abnormalities were also observed. The occurrence of similar deformities across several species from the same area suggests an environmental cause.

Documentation: Browder, J.A., D.B. McClellan, D.E. Harper, M.G. Kandrashoff, and W. Kandrashoff. 1993. A major developmental defect observed in several Biscayne Bay, Florida, fish species. Environmental Biology of Fishes 37:181-188.

University of Miami.

Study of biota deformities as related to historical sediment contaminants in Biscayne Bay. Surveys were conducted from 2/91 to 9/92 in north and south Biscayne Bay to assess the nature and frequency of deformities and diseases in fish and blue crabs. Most frequent external abnormalities included scale disorientation, missing or deformed fin ray or rays, and disruption of lateral line. Others seen were missing fins, fin erosion, concavity in the dorsal profile, subcutaneous hemorrhages, and ulcers. The majority of abnormalities observed were in bony structures. Consistent results showed more abnormalities in the north bay, specifically clusterings of cases at 2 marinas. Historically the north bay had much higher inputs of sewage and urban runoff and most of the sample sites in the historical contaminant database (1983-91) were near more densely populated urban areas in the north bay. The highest levels of contaminants are at the mouths of rivers and canals and near marinas. The prevalence of abnormalities for all fish surveyed was correlated with the concentration of total and aromatic hydrocarbons in sediment samples within 2 km of the survey sites. No correlations were found between contaminant concentrations and the distribution of abnormalities in individual fish species or crab except between sediment copper levels and abnormalities in the blue striped grunt. More recent data on distribution and type of contaminants are needed to implicate or eliminate pollution as a cause of deformities.

Documentation:
Schmale, M.C. 1994. The effect of historical contaminants in biota in Biscayne Bay, Florida. Report No. 5 (final report and summary of study) and Deliverable 8 to South Florida Water Management District (Contract No. C90-1334-3). Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.
Gassman, N.J., L.B. Nye, and M.C. Schmale. In press. Distribution of abnormal biota and sediment contaminants in Biscayne Bay, Florida. Bulletin of Marine Science 54(3).

National Park Service, South Florida Research Center, Everglades National Park.

Analysis of Mowry Canal water quality and discharge. Water quality and land use data from county and federal agencies for the period 1974-81 were analyzed to assess the impact of discharges into Biscayne

Bay. Water quality data from USGS and Dade Co. DERM included physical parameters, nutrients, bacteria, metals, and pesticides. USGS collected data on over 105 parameters in the canal near its mouth from 1975-80. In 1980 and 1981, DERM collected samples for 9 parameters from 4 stations as part of its canal monitoring program. Available data indicated water quality was relatively good. High nitrogen loading (the highest concentrations in the Dade Co. canal system) exists in the area of the north branch of the canal. Agriculture accounts for 52% of land use in the canal basin. Several heavy metals and pesticides (including DDT and its breakdown products, chlordane, dieldrin, and PCBs) were detected in the sediments at the USGS station.

Documentation: Scheidt, D.J., and M.D. Flora. 1983. Mowry Canal (C-103): water quality and discharge into Biscayne Bay, 1975-1981. Report SFRC-83/06. National Park Service, South Florida Research Center, Everglades National Park, Homestead.

City of Miami, Department of Planning, Building and Zoning.

Miami River master plan. Document summarizes existing and proposed projects, programs, and ideas of public agencies and private sector organizations working to improve the river and its environs and presents an action agenda. Exec. Summ. concludes the river should have clean water, meeting all state water quality standards suitable for a major tributary to Biscayne Bay. The river should support a variety of marine plant and animal life, but is not intended to support human recreational activity. Sources of water pollution must be eliminated by capital investments in replacement of outmoded sanitary sewer and stormwater drainage systems and by improvement in regulations and enforcement.

The river is in the center of the most densely developed portion of the Miami metropolitan area. The urbanization of Miami has dramatically altered the river from its natural state and changed the water to conditions that consistently violate water quality standards. Pollution sources include stormwater runoff, leakage and overflow of raw sewage, discharge of bilge and wastewater from vessels, eroding shorelines, leaking fuel and other contaminants from derelict vessels and deteriorating shoreline structures, dumping of fish wastes, suspended sediments that prevent light from penetrating to the river bottom, and potential leakage from vessels involved in an increasing number of accidents and groundings. As the largest tributary in the Biscayne Bay Aquatic Preserve, the Miami River has been a major focus of study.

Stormwater runoff containing suspended solids, nutrients, oil, grease, and possibly trace metals, pesticides, herbicides, and plasticizers, is a major source of pollution. The City of Miami is conducting an extensive retrofitting program on the stormwater drainage basins to provide retention of runoff from the first one inch of rainfall, which carries about 90% of the total pollutant runoff. The second major source of pollution is sanitary sewage. A sewage treatment plant was not opened until 1956; until then raw sewage was discharged into the river directly through outfalls. Acute short-term incidents still occur with heavy rainfall, when large volumes of stormwater and groundwater enter the sewer system causing it to overflow and creating pollutant concentrations hundreds to thousands of times higher than water quality standards. These episodes generally contaminate adjacent portions of Biscayne Bay and even cause overflows through manhole covers in streets. Improvements include: By 1992, stormwater catch basins were supposed to be disconnected from the sanitary sewers, and a new underground force main across Biscayne Bay to replace the present deteriorated one. [6/94 almost completed]. Chronic contamination at lower concentrations, but still tens of times higher than standards, occurs from ongoing pollution of the stormwater drainage systems with raw sewage coming from leaking sewer pipes and from illegal or improper connections to the stormwater drainage system. This problem is so widespread that it is difficult and costly to detect and correct all points of contamination. Another source of sewage contamination is the discharge of untreated waste from vessels on the river. Although this is prohibited, citations can be issued only based on water samples collected at the time of discharge; this is easy for vessels to evade.

Sediments that have accumulated from stormwater runoff, waste disposal, and shoreline erosion in the main shipping channel (dredged in 1932-33) constrain navigation on the river and are a serious threat to water quality in the river and Biscayne Bay due to suspended solids and pollutants in the sediment. The USACOE has calculated that vessel maneuvering width will continue to decrease an average of one foot per year throughout the length of the river. This will make the continuous resuspension of the sediments by vessels a worse problem. The USACOE planned to conduct navigation dredging and dump the sediments at an ocean disposal site, but test results show the sediments are not suitable for such disposal.

The river is the principal landing point for the local fishing fleet of Dade Co., with 59% of the county landings in 1989. The major landings are spiny lobsters and sponges; over 25% of the sponge catch for the entire state was landed on the Miami R. in 1989 (before the 1991 prohibition on sponge fishing in Biscayne NP).

The Miami River is a manatee habitat area, especially in the winter; they typically move each day between resting in the river and other tributaries (Biscayne Canal, Little River, Coral Gables Waterway) and feeding on grass beds in Biscayne Bay. SFWMD is studying alternative ways to prevent manatee deaths related to entrapment in gates of salinity control structure, the largest known cause of death of manatees in Dade Co. The second most common cause of death in collision with vessels.

Documentation: City of Miami, Department of Planning, Building and Zoning. 1992. Miami River master plan. Final report - January, 1992. City of Miami, Department of Planning, Building and Zoning, Miami, Florida.

Miami River Water Quality Plan. Presents much of same background material as in Master Plan. The river is a major tributary to Biscayne Bay. The Miami Canal is the primary drainage outlet for excess water from the Everglades Agricultural Area and the Water Conservation Areas and is a secondary outlet for excess water from Lake Okeechobee. The rapids were dynamited in 1908, and between 1909 and 1933 the system was lengthened, widened, and deepened to create the present 81-mile-long Miami River and Canal. The river and its tributaries up to the salinity control structures are part of the state Biscayne Bay Aquatic Preserve and are classed as Class III waters, for Recreation and Propagation and Management of Fish and Wildlife. The bay basin into which the river discharges is a mix of developed and natural areas, including even a FG&FWFC Critical Wildlife Area. The Miami River watershed is one of the stormwater drainage areas in Dade Co. with the highest theoretical pollutant loading. The river has experienced serious contamination, and water and sediment quality is generally poor....[same general information as in master plan, on sewage, etc.]. Water quality samples have been collected near the river mouth since 1979 under the Biscayne Bay Restoration and Enhancement Program. These samples indicated degraded water quality in the river, and in 1984 6 water quality sampling stations were added in the main river channel. In 1987, in connection with the SWIM Program, another 9 stations were added upstream of the salinity control structures and in Tamiami Canal and Wagner Creek. Additional special sampling is conducted periodically under the SWIM Program.

A potential toxicity threat to non-target marine organisms is the presence of tributyltin, an organotin compound used in antifouling paints. All stations sampled in the Miami River in 1990 and 1992 exceeded the federal advisory limit for this toxic compound, especially in the upstream half of the river, where concentrations reached about 7 times the limit. Similar concentrations were detected at 2 of 24 other stations in the Biscayne Bay system (Dinner Key and Black Creek/Goulds Canal). At the river mouth, concentrations were reduced to near the advisory limit.

A variety of sediment quality studies have been conducted since the early 1980's. The FDNR, FDER, ACE, and DERM found contamination with a variety of hydrocarbons, pesticides, herbicides, trace metals,

and polychlorinated biphenyls, in some cases greater than levels reported for other urban U.S. ports. Bioassay results generally indicate that Miami River sediments are not suitable for ocean disposal.

In 1988, the first stormwater outfall improvement project was completed. The City of Miami has continued stormwater drainage retrofitting projects, utilizing matching local and SWIM program funds. Under SWIM, DERM has attempted to monitor stormwater quality and pollutant loading using automated sampling devices triggered by rainfall and flow in the sewers. The sampling program experienced several problems but was able to document that the stormwater drainage system in the Miami River watershed is contaminated by numerous point and non-point sources of pollutants.

Documentation: Dade County Department of Environmental Resources Management, Natural Resources Division. 1993b. Miami River water quality plan. A report submitted to: The Miami River Water quality Commission, and Appendices B through H. Metro Dade DERM Technical Report 93-3. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

U.S. Army Corps of Engineers, Jacksonville District.

Miami River dredging project. The objective was to produce a comprehensive review, identification, and assessment of alternatives for disposal of contaminated sediments from the Miami River project. The study area was the first 5.5 miles of the 20-mile-long river along the existing Federal channel, bounded upstream by a salinity dam. Most of the deposits are surficial soils eroded and transported from a large watershed area, including much of Dade, Broward, and Palm Beach counties, since the initial dredging to a depth of 15 ft into native porous limestone rock during the 1930s. Drainage water enters the navigation channel via Miami River Canal, South Fork, Tamiami Canal, Wagner Creek, and numerous storm sewers. This urban river was long used as a receptacle and conduit for many types of waste materials, but there has been significant pollution abatement in recent years with improvements in storm and sanitary sewer systems, pollution control and inspections of marine and industrial facilities. Previous studies indicate current major concerns are metals content in the sediments and sanitary hazards related to sewage pollution overflow incidents.

Metal concentrations in Miami River sediments are in general significantly higher than in local soils or in marine sediments elsewhere in the Biscayne Bay system. FDEP sediment samples during 1983-84 showed elevated levels of arsenic, cadmium, mercury, lead, and silver, and the presence of pesticides and PCBs. Samples by DERM during 1983-90 showed elevated metal concentrations in sediments at some locations, especially near industrial outfalls, and presence of organic pollutants such as hydrocarbons, pesticides, and PCBs.

In July 1991, sediment samples were collected through a joint COE-DERM bioassay project to evaluate potential impact of dumping dredge materials at a designated offshore ocean disposal site near Miami. No pesticides or PCBs were detected in the sediments, and metal concentrations were not high enough to cause dredged materials to be classified as "hazardous waste" under Federal or state criteria, but they do not meet local guidelines for unrestricted use as clean fill. The 1991 bioassay tests indicated that Miami River sediments cause levels of mortality in test organisms that exceed Federal criteria for ocean disposal, thus making it necessary to develop upland disposal options.

Because of the possibility of introducing contaminants into previously uncontaminated areas (from resuspension during removal or spills/leaks during transport), the decision to remove contaminated sediments must be made only after careful consideration of non-dredging remedial options. There has never been a maintenance dredging or sediment disposal project on the Miami River. It is speculated that on outgoing tides and riverine flood flows sediments resuspended from channel shoaling and vessel turbulence are transported from the river to Biscayne Bay. The river bottom of the 5.5-mile lower reach

is estimated to contain about 877,500 cubic yards of sediments. Finding suitable sites near the river to store or dispose of the material is complicated. The options of mechanical and hydraulic dredging, special treatment systems for the dredged solids, and disposal sites are evaluated in detail. The sediments do not meet the COE/EPA minimum criteria for open ocean disposal. Inshore options are to fill existing holes in Biscayne Bay with the sediment or create new dredge islands, but permitting would be difficult because the bay is a State Aquatic Preserve and Outstanding Florida Water. Confined disposal in diked containment areas is possible at 2 locations: vicinity of Palmer Lake near the upstream end of the channel and at Virginia Key. Concerns include use of Palmer Lake by manatees and impacts on the critical wildlife area along the northwest edge of Virginia Key. After it was dried or solidified and stabilized, the dredged material could be placed as solid waste in an existing or new upland disposal site meeting all state and local criteria.

The criteria for evaluation of environmental impacts were: groundwater contamination, surface water contamination, air pollution, leaks/spills/accidents, destruction of wildlife habitat/natural areas/wetlands, loss of unique site features, permanent contamination of site, contamination of nearby vegetation or fisheries, traffic congestion, odors, noise, visual ugliness, and effects on the community (image of dumping ground, magnet for heavy industry).

Recommendation: Pump mechanically dredged barge-transported materials to a diked containment area at the north end of Virginia Key. Site is currently being used as a repository for dredge material for the Port of Miami.

Documentation: Gulf Engineers & Consultants, Inc. 1993. Alternatives for the dredging and disposal of sediment from the Miami Harbor (Miami River) project, Florida. Final report. Contract No. DACW17-91-D-0010. U.S. Department of the Army, Corps of Engineers, Jacksonville District, Jacksonville, Florida.

Florida Department of Environmental Protection.

Sediment toxicity in Biscayne Bay.
[waiting for information]

Documentation: Fred Calder, FDEP, pers. comm.

South Florida Environmental Research Foundation.

Limnological survey of Dade County lakes. A physical-chemical survey of 124 rockpit lakes was conducted in 1969; 72 of these were resampled in 1976. The goal was to provide baseline data for future studies on changes in water quality in the lakes. Data from both years were analyzed by a multi-dimensional hyperspace distance program, which clustered the lakes into groups and identified certain lakes as being representative.

Documentation:
Pope, R.L., and P.B. Schroeder. 1979. A limnological survey of Dade County lakes. Abstract. Florida Scientist 42(Suppl.):32.
Schroeder, P., and R. Pope. 1979. A cluster analysis comparison of Dade County rockpit lakes and 1969 and 1976. Abstract. Florida Scientist 42(Suppl.):33.

University of Miami/Florida International University.

South Dade planning studies. Design professionals, government officials, members of civic organizations, and residents attended a workshop to create plans for rebuilding the extensive hurricane-damaged area of South Dade Co. One of the priorities identified in the workshop was that water quality must be protected and controlled to sustain the supply of freshwater to urban, agricultural, and natural systems.

Documentation: University of Miami and Florida International University. 1992. The new South Dade planning charrette: from adversity to opportunity. School of Architecture, University of Miami, and School of Design, Florida International University, Miami, Florida.

REGION

U.S. Geological Survey, Water Resources Division.

Water resources data collection. During each water year (October-September), the USGS obtains a large amount of data on Florida water resources. The data include records of stage, discharge, groundwater levelsm, and water quality of streams; and stage, contents, and water quality of lakes and groundwater wells. In Subregion 9, the data are from 19 surface water (canal) stations, in cooperation with many municipal, county, state, and other federal agencies in the Subregion. Since 1974, the Miami Canal station has been 1 of 22 Florida stations in the National Stream Quality Accounting Network to obtain information to describe areal variability of quality of Nation's rivers, detect changes or trends in water quality characteristics, relate trends to upstream land and water use, account for constituent transport between river basins and into estuaries, and provide a consistent data base for water quality assessment and hydrologic research.

Documentation:
Committee to Review the USGS National Water Quality Assessment Pilot Program. 1990. A review of the USGS National Water Quality Assessment Pilot Program. National Academy Press, Washington, D.C.
Haire, W.J., and C. Price. 1993. Water resources data - Florida, 1992. Volume 2A: South Florida surface water. Water-Data Report FL-92-2A. U.S. Geological Survey, Miami, Florida.

National Water-Quality Assessment Program. The NAWQA Program began in 1986 as a pilot program to describe status and trends in the quality of a large, representative part of the U.S. surface and groundwater resources. It is now a full-scale program that will allow information at different spatial scales to be integrated. There are 60 study units of hydrological systems that include parts of most major river basins and aquifer systems. The first two national topics will focus on pesticides and on nutrients and sediments. Each study unit will have a local liaison committee. Southern Florida is one of the study units. The Atlantic Coastal Ridge will be part of the study because of the vulnerability of its groundwater.

Documentation:
Committee to Review the USGS National Water Quality Assessment Pilot Program. 1990. A review of the USGS National Water Quality Assessment Pilot Program. National Academy Press, Washington, D.C.
Leahy, P.P., and W.G. Wilber. 1991. National Water-Quality Assessment Program. Water fact sheet. Open-file report 91-54. U.S. Geological Survey, Reston, Virginia.
McPherson, B.F. 1994. National Water-Quality Assessment Program - southern Florida. Water fact sheet. Open-file report 94-57. U.S. Geological Survey, Tallahassee, Florida.

National Oceanic and Atmospheric Administration, National Ocean Service, Strategic Environmental Assessments Division.

Survey of agricultural pesticide use in coastal areas. An assessment of the use of the 35 commonly applied agricultural pesticides in U.S. estuarine watersheds was made for 76 crops for the year 1987. Nonagricultural applications (golf courses, etc.) were not included. The Biscayne Bay watershed was not one of the drainage areas with the greatest total pesticide use, but a rating system that considered potential impact to estuarine organisms by normalizing the amount of the most hazardous products used ranked Biscayne Bay 9th in the U.S. Most importantly, a rating system that considers the intensity of this "hazard normalized application" by calculating pounds applied/acre of drainage area/year ranked Biscayne Bay the second worst estuary in the U.S. for per-unit-area application of the more hazardous pesticides. (The most at-risk estuary was Rookery Bay in southwest Florida.) Applications of the insecticides endosulfan (37,000 lbs in the Biscayne Bay watershed) and chlorpyrifos (6,000 lbs) were most responsible for the ratings. Endosulfan is commonly applied to tomatoes and is ranked as the most hazardous pesticide found in the marine environment because of its acute toxicity, ability to concentrate in fish tissue, and long time period to break down in the environment. The drainage basin of Biscayne Bay is 24% agricultural land. In this basin, an estimated 445,000 lbs of the 35 common pesticides are used per year. This total consists of 246,000 lbs of herbicides, 125,000 lbs of insecticides, and 74,000 lbs of fungicides. The compounds with the greatest application were the herbicides atrazine (180,000 lbs) and 2,4-D (37,000 lbs); the insecticides endosulfan and methamidophos (each about 37,000 lbs); and the fungicide chlorothalonil (68,000 lbs).

Documentation:
Pait, A.S., A.E. De Souza, and D.R.G. Farrow. 1992. Agricultural pesticide Use in coastal areas: a national summary. Strategic Environmental Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland.
Humphreys, J. 1993. Nationwide study looks at pesticide threat to estuaries. Fathom 5(2):3-4.

Florida Department of Agriculture and Consumer Services, Division of Agricultural Environmental Services (the lead state agency for regulation of pesticides).

Monitoring of Florida surface waters for pesticides. A state-wide program has recently been initiated to monitor surface water and sediments for pesticides. To assess the extent of pesticide contamination, an inventory of pesticide detections was initiated in 3/93, with information requested from 35 state, regional, and local agencies. 20 agencies responded; 12 provided requested data, among them SFWMD, Dade County, and Palm Beach County. FDEP monitoring in 1991-93 included Broward Co. The SFWMD data set, primarily samples at water control structures, was the most extensive for both surface water and sediment. Sampling by DERM in 1981-90 detected pesticides in Dade Co. canals, creeks and Biscayne Bay that included endosulfan I; heptachlor; P,P'-DDD; P,P'-DDE; P,P'-DDT; perthane; trifluralin; alpha-BHC; 2,3-D; aldrin; dieldrin; and endrin. Results of the inventory may help indicate water bodies affected by agricultural activities and allow actions to be taken to minimize adverse effects.

Documentation: Shahane, A.N. 1994. Pesticide detections in surface waters in Florida. pp. 408-416 *in* A.R. Dutton, editor. Toxic substances and the hydrologic sciences. American Institute of Hydrology, Minneapolis, Minnesota.

NATURAL AREAS/HABITAT RESTORATION/MITIGATION

PALM BEACH COUNTY

Palm Beach County Department of Environmental Resources Management.

Environmentally Sensitive Lands Acquisition Program. A program to purchase, preserve, and maintain ecologically sensitive lands was initiated in 1991 when voters approved a bond issue for $100 million. A consultant conducted an inventory of remaining native ecosystems in the county and identified 38 quality sites that were subsequently proposed for acquisition by a citizens advisory committee. Of these, 14 sites totalling more than 22,400 acres are identified as highest priority. 8 of these 14 sites occur in the central and southern portions of the county that are contained in Subregion 9. Central Palm Beach Co. contains 4 ESL sites. Royal Palm Beach Pines, 736 acres southwest of West Palm Beach, is one of the best remaining examples of the pine flatwoods/wet prairie vegetative association in central Palm Beach Co. Approximately 44% of the site is wetlands, mostly wet prairie. The federally listed bald eagle and wood stork have been seen foraging in the area; the alligator is a resident. The state threatened Florida sandhill crane is a frequent visitor. The 54-acre Seacrest Scrub in Boynton Beach is the largest remaining scrub site in central Palm Beach Co. The 13-acre Rosemary Scrub is also in Boynton Beach. The federally threatened scrub jay is found in Seacrest Scrub, as is the gopher tortoise, a state species of special concern. Acquisition of the fourth site identified, The Water Catchment Buffer site, is now being handled by the City of West Palm Beach (see below).

There are also 4 ESL sites in southern Palm Beach Co. Delray Oaks is a 22-acre site in Delray Beach that contains a high-quality mature live oak hammock and small wetland. Knob Hill, a 52-acre site in Boca Raton is a combination of Florida scrub and oak hammock that provides excellent wildlife habitat. The scrub includes some of the oldest sand pine trees in the county. The site contains the county's largest concentration scrub palmetto, a threatened species on the state list, as well as a viable population of gopher tortoises. The Yamato Scrub, 249 acres in Boca Raton, is one of the most diverse Florida scrub plant communities in the region. It includes oak hammocks, scrubby flatwoods, dry prairies, and freshwater wetlands. The three portions of the Pope John Paul II/IBM/Potomac Scrub comprise 332 acres of high-quality Florida scrub and pine flatwoods.

Most of these sites are known to support gopher tortoises and other rare animals and all contain several rare or endemic plants. All of these tracts are surrounded by development. A shopping mall is proposed for the Knob Hill site; most of the Yamato Scrub has been approved for development. As of 4/94, two small sites have been acquired.

Documentation:

Kay Brennan, Palm Beach Co. DERM, pers. comm.
Steve Farnsworth, Palm Beach Co. DERM, pers. comm.
Palm Beach County Department of Environmental Resources Management. 1991. Palm Beach County environmentally sensitive lands referendum, March 12, 1991. Information sheet, list, and map. Palm Beach County Department of Environmental Resources Management, West Palm Beach, Florida.
Palm Beach County Department of Environmental Resources Management. Undated. Fact sheets on ESL sites. Palm Beach County Department of Environmental Resources Management, West Palm Beach, Florida.

City of West Palm Beach.

Environmentally Sensitive Lands Program. The Water Catchment Buffer site is 579 acres of wet prairie, marsh, swamp, and hammocks southwest of the City and adjacent to the West Palm Beach Water Catchment Area. Federally endangered snail kites nest and feed in the tract. Presently, a road extension is proposed to pass through the site, and completion of Okeechobee Boulevard to 6 lanes is expected to increase development in the surrounding area. The site's acquisition as a preserve is being pursued by the City.

Documentation:
Steve Farnsworth, Palm Beach Co. DERM, pers. comm.
Palm Beach County Department of Environmental Resources Management. Undated. Fact sheets on ESL sites. Palm Beach County Department of Environmental Resources Management, West Palm Beach, Florida.

City of Boca Raton.

Environmentally Sensitive Lands Program. The City passed a $12 million bond issue in 1991 to preserve sites that would improve surface water and air quality, recharge aquifers, provide habit for plants and wildlife, and provide wildlife corridors. A citizen task force evaluated available lands and recommended 10 sites for acquisition. The sites exhibit a variety of habitat, including wetland, red maple forest, cypress swamp, hardwood swamp, live oak hammock, cabbage palm/oak hammock, dry prairie, palmetto prairie, Florida scrub, sand pine scrub, scrubby flatwoods, and pine flatwoods. Individual parcels are as small as 9 acres. The largest (College of Boca Raton/IBM/Yamato Plaza) and second largest (Yamato Scrub) and also in the county's program, as is the Knob Hill site. The 31-acre Weissman site contains a portion of the historic Hillsborough slough, a shallow freshwater river that ran to the ocean. Gopher tortoises were reported from most of the sites. The federally threatened indigo snake was seen on 2 of the sites, 1 of which has already been lost to multifamily residential development.

Documentation: City of Boca Raton. 1991. Environmentally sensitive lands referendum, October 22, 1991. Information sheet, list, map, and descriptions of sites. City of Boca Raton, Boca Raton, Florida.

Florida Atlantic University.

Scrub ecosystem research. Vegetation was studied at 13 remnant scrub tracts in Boca Raton for periods ranging from 1 to 15 years to determine its relation to ridge patterns. Site with the highest elevations had the greatest species richness. Data analysis revealed a surprising diversity, with more total species and a greater mean number of species per site than the more publicized Central Ridge. Also, a recovery study was being conducted in a scrub area on the FAU campus, where a decade of mowing was discontinued in 1973. Frequent mowing caused species richness to drop about 50%, and may have the same effect as fires.

Documentation: Austin, D.F., F.R. Posin, and J.N. Burch. 1987. Scrub species patterns on the Atlantic Coastal Ridge, Florida. Journal of Coastal Research 3:491-498.

Florida Game and Fresh Water Fish Commission, Office of Environmental Services.

Inventory of scrub habitat. An inventory of the Treasure Coast Region included Palm Beach Co. Distribution and condition of scrub habitat were determined by interpretation of published soil surveys, literature review, and infrared photographs and subsequent ground truthing. Recommendations were made on sites to be preserved. The inventory resides in a computerized database and map system.

Documentation: Fernald, R.T. 1989. Coastal xeric scrub communities of the Treasure Coast Region, Florida: A summary of their distribution and ecology, with guidelines for their preservation and management. Florida Game and Fresh Water Fish Commission. Nongame Wildlife Program Technical Report Number 6. Tallahassee, Florida.

Florida Department of Transportation, District 4.

Pond Apple Slough mitigation.
[waiting for information]

Documentation: Laura Burnett, FDOT, District 4, pers. comm.

South Florida Water Management District.

Effectiveness of constructed shoreline to develop littoral habitat. The natural revegetation and benthic production of a constructed open and bermed shelf in Canal 51 were monitored at 3-month intervals between 9/86 and 6/88. The study was in response to a condition for a permit for maintenance dredging of the canal. Results showed that bermed shelves were undesirable due to erosion and entrapment of debris and floating vegetation. *Eichhornia* rapidly colonized the open shelf, and as it increased total benthic organisms decreased. This would be the dominant species in a littoral shelf environment if herbicidal control is eliminated.

Documentation: Rutchey, K. 1992. The response of vegetation and benthic macroinvertebrates to constructed littoral habitat in Canal 51. Technical Memorandum. Environmental Sciences Division, Research and Evaluation Department, South Florida Water Management District, West Palm Beach, Florida.

BROWARD COUNTY

U.S. Environmental Protection Agency.

West Broward Advanced Identification (ADID) Study. In 1991, an ADID study identified sensitive wetlands in a 30,000-acre area west of I-75. This area is subject to intense development pressure, drainage, and habitat alteration. 20% of the wetlands were designated unsuitable for fill; 27% were designated for case-by-case review; 53% were designated "suitable with appropriate mitigation."

Documentation: U.S. Environmental Protection Agency. 1994a. South Florida wetland planning activities, advance identification (ADID) wetland planning projects. Wetlands Planning Unit, United States Environmental Protection Agency, Region 4, Atlanta, Georgia.

Florida Department of Transportation and City of Dania.

Saw palmetto transplant project. The FDOT recently tested a new transplant technique for saw palmetto in an experimental planting of 74 plants in a median strip in Griffin Road. All are surviving. They have also been planted at the loop of Dania Beach Blvd. and A1A. DOT had not previously been able to grow palmetto transplants in South Florida. Saw palmettos will be planted near Fort Lauderdale-Hollywood International Airport and along other roadways during the next 3 years. This is a very hardy and low-maintenance native that does not need irrigation or pesticides and will beautify and protect from erosion areas that are now barren, such as steep roadside embankments and overpasses.

Documentation:
Carl Higgins, landscape architect, Florida DOT, District 4, pers. comm.
Kollin, J. 1994. Unkillable shrub soon to be planted roadside. Tropical Trails (Spring 1994):4-5, as reprinted from the Sun Sentinel.

Broward County Community Services Department, Parks and Recreation Division.

Environmentally Sensitive Lands Acquisition Program. A program to purchase, maintain, and enhance sensitive lands in Broward Co. was initiated in 1989 when voters approved a bond issue for about $75 million. The resources of a site, including natural and historic characteristics, are inventoried. The extent of invasion by exotic plants and animals is evaluated and remediated. Management strategies are developed for the physical protection, restoration, enhancement, and revegetation to maintain the natural ecosystem function of the sites. As of 6/94, 18 sites have been acquired and another is in process of acquisition. The habitats include pine flatwoods, cypress/slash pine, cypress wetland, maple/cypress, scrubby flatwoods, sand pine scrub, low and high hammock, pond-apple wetland, saltmarsh/mangroves, and sawgrass prairie. The sawgrass prairie tract was recently purchased as an Everglades buffer strip with SFWMD and other state funds. The Flamingo Road site, with 155 acres of high hammock, is the largest ESL and occupies the western portion of the Long Key ridge, formerly an island in the Everglades. Pine Island Ridge, 101 acres of high hammock with some remnant slash pines, is the next largest site and the highest elevation in Broward Co. The 97-acre Miramar Pineland contains what may be the oldest and largest slash pines in Broward Co. Most of the other sites are under 40 acres in size. One of the smallest, the 11-acre Coconut Creek Maple Swamp, contains prime examples of bald cypress, red maple, and pond-apple trees. The hardwood swamp forest has retained its health because area farmers have pumped excess water into it. The 24-acre Crystal Lake site is an outstanding example of the very rare sand pine scrub community. The 20-acre Military Trail site is the only scrub site in Broward Co. ownership that protects a complex of high scrub, scrubby flatwoods, and remnant cypress. The site is a relocation site for the gopher tortoise, a state species of special concern. 2 additional sites (a 10-acre willow pond and 13 acres of cypress/slash pine) are approved for acquisition.

Documentation:
Gil MacAdam, Broward Parks & Recreation Div., pers. comm.
Broward County Parks and Recreation Division. Undated. Fact sheets on ESL sites. Broward County Community Services Department, Parks and Recreation Division, Oakland Park, Florida.
Broward County Parks and Recreation Division. Undated. Resource management for 1989 Environmentally Sensitive Lands bond issue sites. Broward County Community Services Department, Parks and Recreation Division, Oakland Park, Florida.
Broward County Parks and Recreation Division. 1993. Environmentally Sensitive Lands Bond Program, Broward County, Florida - March 1989. Map and table, 10/27/93, as revised. Environmental Section, Broward County Parks and Recreation Division, Oakland Park, Florida

West Lake Mitigation Program. West Lake is a 1400-acre coastal wetland and mangrove preserve with 262 acres of open lake that extends for 3 miles along the Intracoastal Waterway in Hollywood. It is operated as a county park. Although surrounded by dense residential and industrial development, including a major port, airport, and highways, West Lake is the best example of mangrove community remaining in Broward Co. and the largest of its kind between West Palm Beach to Miami. Its purchase in 1985 was the result of an 11-year effort led by the Broward Co. Commission, City of Hollywood officials, community leaders, and environmental groups. The purchase agreement included almost 200 acres of wetland creation that involved removal of elevated zones of Australian pines, creation of lower elevation wetland, and creation of channels in the wetland to allow mangrove propagules to naturally seed the site. This is one of the largest mitigation projects ever conducted in Florida. About 123 species of birds have

been observed at the site, including 20 considered endangered, threatened, or rare in Florida. West Lake is an important nursery area for fish, especially for the snook, a state species of special concern.

Documentation:
Gil MacAdam, Broward County Parks and Recreation Div., pers. comm.
MacAdam, G. 1990. Environmental protection through citizen action. Parks and Recreation 25(October):46-51.
Broward County Parks and Recreation Division. 1989. West Lake Mitigation Program. Fact sheet. Public Service Department, Broward County Parks and Recreation Division, Oakland Park, Florida.

Tree Tops Marsh Restoration Project. This 24-acre project in Tree Tops Park was completed in 1991 and includes a 4-acre lake, 11-acre marsh, 3 acres of hammock islands, and 6 acres of transitional zone. It was funded by the Broward Co. Office of Integrated Solid Waste Management to mitigate the impacts to wetlands during construction of an incinerator. The goals were to restore the pre-drainage condition of the lowland, enhance wildlife and fisheries habitat and diversity, in addition to provide educational and recreational opportunities.

Documentation: Broward County Parks and Recreation Division. 1992. Tree Tops Marsh Restoration Project: an overview. Interpretive Section, Broward County Parks and Recreation Division, Oakland Park, Florida

Urban Wilderness Inventory. An Urban Wilderness Advisory Board maintains an inventory of existing natural areas and makes recommendations to the County on acquisition and regulation of these areas. Preservation of environmentally sensitive areas is accomplished through designation as Urban Wilderness Areas; these form the Urban Wilderness Park System. Several of the Environmentally Sensitive Land sites have been proposed as part of this system. One urban wilderness area is Fern Forest Nature Center, 254 acres with 10 plant communities and remnants of the historical Cypress Creek floodway. Another is Tivoli Sand Pine Preserve, 23 acres comprising one of the largest remaining stands of sand pine in the county.

Documentation:
Broward County Board of Commissioners. 1993b. Broward County, Florida, comprehensive plan 1989. Volume 4, support documents, as amended through December 10, 1993. Broward County Planning Council, Fort Lauderdale.
Broward County Parks and Recreation Division. Undated. Fact sheets on ESL sites. Broward County Community Services Department, Parks and Recreation Division, Oakland Park, Florida.
Broward County Parks and Recreation Division. 1992. Fern Forest Nature Center. Brochure. Broward County Community Services Department, Parks and Recreation Division, Oakland Park, Florida.

Florida Atlantic University.

Scrub ecosystem research. A study of scrub sites included a site at Broward Co. Executive Airport.

Documentation: Austin, D.F., F.R. Posin, and J.N. Burch. 1987. Scrub species patterns on the Atlantic Coastal Ridge, Florida. Journal of Coastal Research 3:491-498.

1000 Friends of Florida/The Conservation Fund.

Broward County Greenways Network. As part of the Florida Greenways Program, this network will provide open space linkages between communities in an intensely urbanized region through use of predominantly man-made waterways. It will focus on the central and south portions of county, specifically the New River, the SFWMD canal system, and the Intracoastal Waterway in the vicinity of Port

Everglades. Lead partners will be Broward County and SFWMD. Phase I (1993) focused on resource assessment, identification of issues, planning workshops, and preparation planning documents. Phase II (1994) will include more detailed network planning and strategy development. Phase III will be implementation during the next 3-5 years.

Documentation: 1000 Friends of Florida/The Conservation Fund. Undated. Broward County Greenways Network project synopsis. Florida Greenways Project. 1000 Friends of Florida/The Conservation Fund. Tallahassee, Florida.

Blueways Project. This is a joint private/public effort to develop an aquatic version of the greenways project in order to maintain open space, create habitat linkages, and further development of recreational opportunities. The New River is considered a good candidate for this project because of its natural, geographical, and social characteristics. Initial stages have included meetings to organize a committee to develop a Blueways plan, find funding support, and develop public interest.

Documentation: Broward County Department of Natural Resource Protection. 1993. New River study: final report. Technical Report Series TR: 93-06. Broward County Department of Natural Resource Protection, Fort Lauderdale, Florida.

DADE COUNTY

Dade County Department of Environmental Resources Management.

Pineland inventory, conducted in 1991 provided baseline information about distribution of Dade Co. pinelands prior to Hurricane Andrew. A followup survey was done after storm at 18 sites, including county and private lands.

Documentation: Joe Maguire, Project Supervisor, DERM, pers. comm.

Richmond Pineland Planning and Management Project, funded by $20K from FWS (under its Tropical Florida Recovery Project for Plants) and $20K from the Dade Co. Tree Trust Fund. Formerly the site of the Richmond Naval Air Station, these pine rockland forests surrounding Metrozoo are the best example of this habitat in Dade Co. and are habitat for 3 federally endangered plants. Over 1400 acres of pineland occur within the 4-sq-mi Richmond area, by far the largest remaining tract of pineland outside of ENP. The land is owned by 9 federal and 2 county agencies and because of this multiagency ownership, the DERM and FWS determined a comprehensive management plan is necessary. Detailed assessment is needed of exotic pest plant control strategies, status of endangered plant species, and wildfire control and prescribed burning needs. Information will be mapped on GIS and groundtruthed. Final plan due about mid-June.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Avino, J.G. 1993. Resolution authorizing the disbursement of funds from the Dade County Tree Trust Fund for the development of a comprehensive forest management plan for the Richmond pinelands. Resolution No. R-745-93. Dade County Board of Commissioners, Florida.
Dade County Department of Environmental Resources Management. Undated. Computerized pineland and hammock forest inventory for Dade County. Draft project description, Hurricane Andrew urban reforestation grant application. Metropolitan Dade County Department of Environmental Resources Management, Upland Planning Program, Miami, Florida.

Endangered Pine Rockland Plant Species Recovery Project, continuing cooperative agreement with FWS. 1) 1992-93 surveys on 5 listed plant taxa determined population status and distribution. First herbarium research defined potential range of each taxa. Next, the Dade Co. Natural Forest Community database was used to identify extant sites within the potential range. Ordination analysis provided indications of habitat quality and suitability and helped prioritize sites for field surveys. The locations of sites found to contain listed taxa were digitized into the county's GIS database. 2) 1992-93 biological monitoring on certain taxa included life history observations, growth studies, and effects of burning.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Dade County Department of Environmental Resources Management. 1993. Endangered pine rockland plant species recovery project. Draft annual report. Dade County Department of Environmental Resources Management, Miami, Florida.

Pine rockland restoration plan following Hurricane Andrew. A series of objectives for monitoring and research is presented, considering the severe reduction of mature slash pine canopy in central and southern Dade Co., delayed mortality from physical tree damage and infestations of bark beetles and weevils, invasion of introduced plant species, pine life history and reproductive cycle information, need for restoration and maintenance of fire, and protected species (FWS lists 5 pine rockland plant species as endangered and 12 species as candidates for listing; FG&FWFC includes 32 pine rockland plants on its list of endangered and potentially endangered state biota). The first goal is to restore and maintain environmentally endangered pine rocklands to preserve their natural resource values by employing appropriate management techniques. Its objectives are to a) re-establish south Florida slash pine in pine rockland habitats affected by Hurricane Andrew, b) restore and maintain naturally occurring plant and animal associations of the pine rockland habitat, and c) ensure the viability of rare, threatened, endangered, endemic species and species of special concern consistent with the preservation and enhancement of pine rockland habitat. The second goal is to achieve a pine rockland forest canopy and understory structure to maximize biotic diversity, with the objective to restore and maintain a forest canopy structure of uneven-aged pine trees and an understory with a mosaic of shrub gaps. Specific actions are presented under each objective.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Dade County Department of Environmental Resources Management. 1994. Dade County pine rockland restoration plan following Hurricane Andrew. Draft document. Dade County Department of Environmental Resources Management, Miami, Florida.

Computerized pineland and hammock forest inventory for Dade County. Application by DERM Upland Planning Program for $25K from Hurricane Andrew Urban Reforestation Grant Program (administered by Florida Dept. of Agriculture & Consumer Services; funds from federal Dire Emergency Supplemental Appropriations Bill). Goal is to map and classify natural pineland and hammock sites, both public and private, in a GIS database. The project has 4 components: pine rockland classification, pine canopy status survey, hardwood hammock classification, and exotic impacts assessment. Sites already being inventoried by other projects will not be included.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Dade County Department of Environmental Resources Management. Undated. Computerized pineland and hammock forest inventory for Dade County. Draft project description, Hurricane Andrew urban reforestation grant application. Metropolitan Dade County Department of Environmental Resources Management, Upland Planning Program, Miami, Florida.

Prescribed Fire Task Force. Formed with DERM, Park & Recreation Dept., Florida DOF, and Metro-Dade Fire Dept. to address urban prescribed burning and implement county-wide wildland fire management program.

Documentation: Dade County Department of Environmental Resources Management. 1993. Endangered pine rockland plant species recovery project. Draft annual report. Dade County Department of Environmental Resources Management, Miami, Florida.

Crandon Park natural areas protection and restoration. At the north end of Key Biscayne, this park consists of 904 acres of uplands and wetlands and 1228 acres of submerged land. Natural areas include sand dune (one of two natural dune systems left in Dade Co.), coastal strand hammock (the only remaining one in Dade Co.), mangrove, salt marsh, submerged land in Biscayne Bay (including hard bottom and seagrass flats), and a unique fossilized mangrove reef thought to be the only one of its kind. The relatively intact natural systems are a rarity in the urban landscape of the southeast Florida coast. The park beaches provide nesting sites for loggerhead and green turtles. The park is also only one of 5 known sites of the beach jacquemontia, an endangered endemic member of the morning glory family, and habitat for the Biscayne prickly ash, a rare tropical tree. In 1976, the north portion of the park was designated a National Environmental Study Area by the U.S. Department of Interior. Recently Dade Co. designated the northern 200 acres of Crandon Park as Bear Cut Preserve. The goal of the natural areas monitoring is to ensure the perpetuation of the coastal strand habitats and mangrove biotic communities through effective ecological management based on current scientific information. Fairchild Tropical Garden initiated a pilot project to compile an inventory of exotic and native flora, identify target taxa, gather phenological data for the taxa, and monitor changes. A long-term monitoring was proposed, including photomonitoring. Major efforts will involve removing exotic vegetation; replanting with site-specific native plant material, utilizing site-specific germplasm when possible; and scrapedowns of existing Australian pine communities to create proper conditions for mangrove and saltmarsh revegetation. Ecological monitoring was also to include bird rookeries. Since Hurricane Andrew, FEMA funds have been used to remove Australian pines, county crews are using herbicides to remove exotics, and volunteers are removing exotics from the beach dunes.

Documentation:
Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.
Dade County Park and Recreation Department. 1991. Crandon Park, natural areas protection plan. Metro-Dade County Park and Recreation Department, The Nature Conservancy, and Fairchild Tropical Garden, Miami, Florida.
Makemson, J., K. Mayo, and J. Sonnenberg. 1992. Bear Cut Preserve in Crandon Park environmental restoration and management study. Metro Dade Park and Recreation Department, Miami, Florida.

Crandon Park wetlands re-creation. As one element of the Bear Cut Preserve at the north end of Crandon Park on Key Biscayne, Dade Co. is re-creating a 17.3-acre wetland as mitigation for impacts association with construction of a replacement sewage force main across Biscayne Bay. The wetland will be re-created in areas that were filled about 40 years ago during construction of the Rickenbacker Causeway and the Crandon Marina boat basin and were covered with Australian pine and other invasive exotic species, until they were cleared after Hurricane Andrew. The wetland will consist of mangrove, saltmarsh, tidal creeks and ponds, and freshwater/brackish prairie and will incorporate an existing Earth Day hammock as a tree island in a saltmarsh prairie. Planting was scheduled to begin sometime between 2/94 and 5/94. 3 wells will be installed to 10-ft depths to determine profile of the site's freshwater lens and the depth of scraping needed for the marsh. The project was designed cooperatively by the Metro-Dade Water and Sewer Authority and their consultants, Park and Recreation Department, DERM, FIU, and the Audubon Society.

Documentation:
Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.
Grossenbacher, C. 1993. Dade County to recreate wetlands at Crandon Park. News release, August 24, 1993. Coastal Resources Section, Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Seagrass mitigation. As mitigation for impacts association with construction of a replacement sewage force main across Biscayne Bay, Dade Co. will plant seagrass over the new pipe once it is installed and also in prop scars in the vicinity of Virginia Key.

Documentation:
Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.
Grossenbacher, C. 1993. Dade County to recreate wetlands at Crandon Park. News release, August 24, 1993. Coastal Resources Section, Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Wetlands re-creation at H/DME site. A 1.5-acre site at the NOAA Atlantic Oceanographic and Meteorological Laboratory on Virginia Key is being returned to a wetland by clearing exotic species and lowering existing grades. As of 6/94, the site has been cleared and is being replanted with native wetland vegetation. This project is mitigation for an antenna erected by the FAA on the grounds.

Documentation:
Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.
Federal Aviation Administration. 1994. Project specifications, environmental restoration of the H/DME site on NOAA property, Virginia Key, Miami, Florida. Phase 1: Earthwork and Phase 2: Planting. FAA-SO-1188, January 26, 1994, and modifications to drawings and specifications, March 16, 1994. Department of Transportation, Federal Aviation Administration, Southern Region, Atlanta, Georgia.

Virginia Key Beach Park restoration. Coastal hammock and strand will be restored here as mitigation by the City of Miami for mangrove damage sustained during burning of hurricane debris. State and federal funds received by the City will be transferred to DERM for the project design. Also, dunes and mangroves destroyed by dredging conducted by the Seaport will be mitigated.

Documentation:
Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.

Biscayne Bay Restoration and Enhancement Program. Many habitat restoration projects are included under this program and are coordinated by DERM. The projects are funded by grants from the Florida Inland Navigation District through cooperative agreements with SFWMD and by the Port of Miami Mitigation Fund. Support is also provided by the Biscayne Bay Trust Fund.

Spoil island restoration. Beginning in 1988 with the Bay Island Enhancement Project, many spoil islands in north Biscayne Bay, formed during construction of the Intracoastal Waterway, are being restored. Projects are presently being carried out on about 15 spoil islands to stabilize the shorelines, remove exotic vegetation, and plant with native trees, and even create sand dunes.

Oleta River State Recreation Area restoration. One of the largest projects in the program is at this park in north Dade Co. DERM has been doing 3 major restoration projects at this park for about 5 years: 1) stabilizing shoreline with limerock boulders and mangrove plantings; 2) scraping about 15-20 acres of Australian pine uplands, creating channels, and planting mangroves; 3) replanting hammock vegetation on 15-20-acre Beer Can Island in the Biscayne Bay portion of the park.

Mangrove plantings and shoreline stabilization. In combination with shoreline stabilization projects using limestone boulders, mangrove planters have been installed in several areas, including Oleta River SRA (funded by Florida DOT), Florida International University North Campus, and David Kennedy Park in Coconut Grove. The mangrove restoration at Oleta River SRA is one of the largest ever completed in Dade Co. and involved planting 32,000 red mangrove seedlings in the Oleta River Mangrove Preserve.

Artificial Reef Program. The installation of artificial reefs in Biscayne Bay provides habitat for marine organisms and fishing areas for recreation. In 1991, about 30,000 tons of natural limerock boulder riprap were placed on 7 reef in north and Central Biscayne Bay. Most of the reefs are constructed in existing dredged depressions.

Filling program for dredged depressions in north Biscayne Bay. Many troughs and borrow areas were created in the bay bottom during construction of causeways, fill islands for housing, etc. during the 1920s-30s. An inventory was made of potential fill areas based on physical conditions and potential for environmental enhancement, and alternative methods for filling the depressions were evaluated. The 16 spoil islands in the north bay were also evaluated for potential to contribute to future enhancement of the bay. 2 components are included in the restoration: 1) a pilot project to fill the dredge holes and replant with seagrass; 2) an artificial reef project at 5-10 sites to fill the holes with boulders.

Documentation:

Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.

Gary Milano, DERM, pers. comm.

Biscayne Bay Management Committee. Undated(a). State of the bay. Special guide to Biscayne Bay 1989-90. Biscayne Bay Management Committee, Miami, Florida.

Biscayne Bay Management Committee. Undated(b). State of the bay 1991-1992. Annual report of the Biscayne Bay Management Committee and a special guide to Biscayne Bay. Biscayne Bay Management Committee, Miami, Florida.

Coastal Technology Corporation. Undated. Filling program for dredged depressions in north Biscayne Bay. Metro-Dade DERM Technical Report 89-10. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Coastal mitigation projects in South Dade Co. There are 2 major projects: 1) The owners of the Old Cutler Bay property are being made to mitigate in order to develop the land; their mitigation activities include land at the Deering Estate and backfilling a canal at Turkey Point. 2) The seaport is mitigating dredging activities by scraping and restoring to mangroves 2 areas (one at the northeast corner of Saga Bay development, another north of Convoy Point in BNP), including removing any roads down to the Bay; also many acres of artificial reefs are being installed.

Documentation:

Craig Grossenbacher, Coastal Resources Section, DERM, pers. comm.

Southwest Biscayne Bay Advance Identification (ADID) project. The project was initiated as a result of a recent evaluation process for a subdivision in southeast Dade Co. The evaluation served to point out that there was increased interest in developing the area, and controversy surrounding the decision on which wetlands should be preserved in the project resulted in a consensus among regulatory agencies that the wetlands in the entire area should be examined through the ADID process. The ADID was requested by Dade Co. in 1990. The ADID project area lies along the southeastern shoreline of Dade Co., between Matheson Hammock Park on the north (north of which shoreline is essentially developed), the cooling canals of the Turkey Point Power Plant on the south, and a boundary on the west where most of the lands were either developed or actively farmed. These lands are influenced by the coastal environment, had a high potential for being jurisdictional, were largely in private ownership, and had high potential for

development in the near future. The purpose of the ADID project is to facilitate the Section 404 permitting process by identifying, in advance of any permit application, those sites for which the discharge of dredged or fill material would not likely comply with the Section 404(b)(1) Guidelines. The project was carried out through GIS mapping and functional assessment of the wetlands.

The area encompasses about 23,000 acres of land, of which about 14,000 (62%) are wetlands. 11 different wetland cover types were found: 72% was coastal native wetland cover (coastal band mangrove, dense scrub mangrove, sparse and/or low scrub mangroves, white mangrove/buttonwood), 6% freshwater wetlands cover (cattail, sawgrass, willow), and 22% dominated by exotic vegetation (primarily Brazilian pepper and Australian pine, some Melaleuca). Herbaceous flats was the most limited vegetation type, comprising only 0.5% of the wetlands. This wetlands area is uniquely important in its biological function because it forms a nearly unbroken chain along the coast, interrupted only by an occasional development and drainage channels, forming a semi-continuous corridor for wildlife movement within and between habitats in the region. Although greatly affected by the man-made drainage system, these communities show demonstrably high value for wildlife food and habitat, storm surge protection, aquifer recharge and prevention of saltwater intrusion, dynamic storage, sediment trapping, and erosion control. Even exotics-dominated areas serve as buffers between the native areas and development and as corridors between native-dominated areas. It would be difficult to justify any management strategy other than preservation and restoration. The continuing health of the entire nearshore Biscayne Bay system depends on maintenance of a healthy vegetated shoreline. 5 federally endangered species and 3 threatened species have been observed in the area. 2 other observed species are listed as threatened by the state and 6 others are listed as species of special concern by the state. Additionally, Dade Co. lists 3 other species seen in the area as threatened, 9 others as species of special concern, and 3 others as rare.

Three designations related to the suitability of an area for disposal of fill were developed. The designation of "Generally Unsuitable" was assigned to all wetlands dominated by native vegetation. 79% of the jurisdictional wetlands received this designation; 44% of these are public lands or if privately owned are within BNP. "Evaluation Required on a Site by Site Basis" was assigned to exotics-dominated areas (11% of wetlands; mainly Australian pine) where the functional assessment was mixed but of generally high value. "Potentially Suitable with Appropriate Mitigation" was assigned to areas with modest values for wetland functions and where filling and development would not result in significant degradation, providing suitable mitigation would replace their functions. These areas (7% of wetlands) are usually completely isolated by some form of development and dominated by Brazilian pepper or Melaleuca. Potential mitigation projects in the area could include: restoring short-hydroperiod wetlands (especially herbaceous wetlands in areas where a tidal connection is possible), restoring buffers for undeveloped lands, re-establishing hydrologic continuity (including removal of roads that penetrate wetlands), scraping down spoil piles along mosquito ditches to match the elevation of the surrounding wetlands and even backfilling the ditches is they are found to have a net negative effect, purchasing land affected by any increase in local hydroperiod west of L-31E, and developing on a large scale a freshwater spreader system east of L-31E.

The entire ADID area was extensively damaged by Hurricane Andrew in 8/92, with the wetlands mapped as Coastal Band Mangroves most severely affected. The functional assessment should now include acknowledgment that most of the wetlands in the ADID area were inundated and helped attenuate the storm tide. It is recommended that when permit applications are considered for areas designated as "Site by Site Evaluation Required" or ""Potentially Suitable" due consideration is given to the future consequences of loss of the protective buffer. Site plans or compensatory mitigation plans should provide for preserving and/or replacing this buffering function.

Documentation:

Burzycki, G.M., and D.L. Drum. 1992. Technical summary document, environmental/regulatory planning for the SW Biscayne Bay wetlands (advance identification of disposal areas). Final draft. Metro-Dade Department of Environmental Resources Management, Miami, Florida.

U.S. Environmental Protection Agency. 1994a. South Florida wetland planning activities, advance identification (ADID) wetland planning projects. Wetlands Planning Unit, United States Environmental Protection Agency, Region 4, Atlanta, Georgia.

South Dade wetlands vegetation mapping. The portion of Dade Co. south of S.W. 344 St. (Palm Dr.) includes a large expanse of undeveloped wetlands important to the health of Biscayne Bay, Card Sound, Barnes Sound, and Florida Bay. Prior to construction of the railroad to Key West, these wetlands were continuous and connected to the Everglades watershed. The railroad was the beginning of increased subdivision and impoundment by a network of levees, canals, and roads constructed for drainage, flood protection, and transportation. These alterations have cut off freshwater flows and allowed encroachment of marine species into wetlands, reduction in mangrove size and productivity, changes in vegetation composition, and invasion of exotics. The wetlands are habitat for several endangered species, including Florida panther, Cape Sable sparrow, and American crocodile. Over 47,000 acres of these wetlands (North C-111 Basin and Model Land Basin) are top priority for purchase by Dade Co. under the EELAP. Vegetation mapping is one of the baseline studies needed for this area and is particularly important because Hurricane Andrew may have significantly altered the vegetation composition. The primary objective is to develop an accurate baseline vegetation map in GIS format for the area. The effort will be compatible with similar projects being conducted for ENP, BNP, and BCNP. A second objective is to investigate the utility of remote sensing for detecting encroachment of invasive species. Phase I of the work will be development of the baseline map; phase 2 will be a focused study of exotic encroachment. The work will be conducted by DERM under contract to SFWMD. Completion of the project is expected 2 years after contract execution.

Documentation:

Burzycki, G. 1994. Letter to C. Goodyear dated February 22, 1994. Metro-Dade Department of Environmental Resources Management, Miami, Florida.

Dade County Department of Environmental Resources Management. Undated. South Dade wetlands vegetation mapping statement of work. Draft. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

National Bulk Carrier's site restoration. Dade Co. DERM purchased this 700-acre site in South Dade Co. from The Nature Conservancy in 1991 in order to restore and protect its wetland habitat value and functions. The site lies just east of Homestead Air Force Base, is bordered on the east by the L-31E Canal, and is bisected by Military Canal. Water table drawdown by the canal network has severely impacted the native wetland communities, with substantial exotic vegetation invasion. USEPA had funded a mapping project that showed viable mangrove and freshwater communities still existed. The land was 52% exotics-dominated wetland, 27% dense scrub mangrove, and 19% white mangrove secondary forest. The project was to proceed with biological and hydrological assessment; evaluation of the feasibility of various restoration techniques; development of detailed restoration plan specifications; and implementation of the plan. However, in 8/92 the eye of Hurricane Andrew passed directly over this site, severely damaging vegetation and complicating and delaying surveys, clearing, water-level well installation, etc. Efforts are concentrated on removing and mulching exotics on 136 acres on the west side of the property. Completion of the final restoration plan is still scheduled for fall 1994, although individual deliverables have been delayed. It is proposed to leave standing mangroves alone, create a 150-ft-wide open water area with islands of willow, pond apple, and buttonwood, create interconnecting channels and isolated ponds, and control exotics on the rest of the property while it naturally revegetates to a short-hydroperiod wetland.

Documentation:

Dade County Department of Environmental Resources Management. 1994. Progress report for October-December 1993. Wetland restoration plan for the National Bulk Carrier's site (#C-3259-A1, Scope of

Work 2.0). Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.
Dade County Department of Environmental Resources Management. Undated. Scope of work 2.0. Wetland restoration plan for the National Bulk Carrier's site. Pages 4-5, Exhibit "A" - C-3259-A1, and maps. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida. Notes by C.Goodyear from presentation by G. Burzycki to DCFNPS 4/26/94.

Wetland basins analyses and management plans. A program has been initiated for developing plans for all wetland basins facing development or pressure of agricultural use. The plans will address water retention, drainage, and mitigation for loss of wetlands habitat. The priority area is the Bird Drive Everglades Basin, 12½ square miles between Tamiami Trail on the north and Kendall Drive on the south and west of Krome Ave. Wildlife-habitat values are being determined in cooperation with COE, USFWS, FDER, and SFWMD. Second priority is the North Trail basin, north of Tamiami Trail, south of 25 St. NW, and west of the Turnpike. Third priority are the wetlands of southeast Dade Co.

Documentation: Metro-Dade County Planning Department. 1989. Conservation, aquifer recharge and drainage element support component. Metro-Dade County Comprehensive Development Master Plan for 2000 and 2010, effective December 1988. Metro-Dade County Planning Department, Miami, Florida.

Environmentally Endangered Lands (EEL) Covenant Program. Ordinance approved by Dade Co. Board of Commissioners in 12/79 allows qualifying property owners to enter into 10-year covenants with the county, stipulating that their property will be maintained in its natural state, subject to one or more conservation restrictions. Purpose is to provide economic incentive for owners of environmentally endangered lands, such as hammocks and pinelands, to preserve their land. DERM evaluates all applications; approval of qualifying lands is done by the Board. Covenanted properties receive preferential tax treatment by a substantial reduction in assessed value.

Documentation: Dade County Department of Environmental Resources Management. Undated. Environmentally Endangered Lands (EEL) Covenant information. Fact sheet. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Technical assistance program is being started to provide restoration advice to private landowners who own natural forests.

Documentation: Klein, J. Undated. South Dade rockland hammocks. Fact sheet. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Lead recovery at Trail Glades Gun Range. Recovery plan is being developed for lead shot over the 600 acres of sawgrass at the western edge of urban area (at Tamiami Trail and Krome Ave.). Groundwater monitoring and soil tests are included. No habitat mitigation is planned because *Melaleuca* is already present west of the area.

Documentation: Rob Line, Park & Recreation Dept., pers. comm.

Mitigation at Milton E. (Emmy) Thompson Park. A conservation land bank was set up in this state-owned land in northwest Dade Co. off Krome Ave. (bordered on west by Dade-Broward Levee; in same area as proposed buffer lakes). The land is mitigation for a landfill (Metro-Dade Solid Waster Management) and for a developed area north of Kendall Drive. Site was originally homogeneous sawgrass; is now 30% *Melaleuca* that spread from plantings when the site was a campground developed by the Corps of Engineers in the 1950s. *Melaleuca* control is being attempted here because it has not spread much into the conservation area to the west. There is a $1M program to conduct aerial (helicopter) spraying of

Melaleuca heads with various combinations of herbicides while waiting for development and approval of biological controls. Permits have been obtained for the spraying. Efforts will also involved mechanical control along with prescribed burning.

Documentation:
Rob Line, Park & Recreation Dept., pers. comm.
McHargue, L., and R. Hammer. 1994. Metro Parks' natural areas management. Garden News 49(2):15-16. Fairchild Tropical Garden, Miami, Florida.

Dade County Park and Recreation Department, Natural Areas Management Section.

Natural areas mapping. GIS- and GPS-based mapping is being done for 790 acres of uplands, including the Deering Estate, Matheson Hammock, Metrozoo/Larry & Penny Thompson Park, and Tamiami Pineland. The Univ. of Wisconsin Institute for Environmental Studies is supplying the computer equipment and software and setting up the computerized systems for assembling map layers and analyzing remotely sensed images. This is a joint effort with Fairchild Tropical Garden. Due to be completed by August 1994.

Documentation:
Dade County Department of Environmental Resources Management. Undated. Computerized pineland and hammock forest inventory for Dade County. Draft project description, Hurricane Andrew urban reforestation grant application. Metropolitan Dade County Department of Environmental Resources Management, Upland Planning Program, Miami, Florida.
Fisher, Jack B. 1994. Biological monitoring project. Garden News 49(2):36. Fairchild Tropical Garden, Miami, Florida.

Post-hurricane natural areas recovery program. Received $5.5M for 3-year program; is largest local funding for natural areas restoration in history of U.S. Objectives are to: 1) remove exotic plant species in severely threatened areas; 2) coordinate with the DOF to conduct prescribed burns to reduce the fuel load and fire threat; and 3) revegetate natural areas destroyed by post-hurricane activities (e.g., dump sites, military staging areas) before exotic plants invade. Program will eliminate immediate threats that would otherwise destroy sensitive natural areas. By the end of 3 years, the areas should be able to recover on their own. Program emphasizes recovery of hammocks; at the time of funding, no one considered pinelands seriously threatened.

Documentation:
Maureen Gregg, Natural Areas Administrator, Park & Recreation Dept., pers. comm.
Dade County Park and Recreation Department. Undated. Post-hurricane natural areas recovery program. Executive summary. Metropolitan Dade County Park and Recreation Department, Natural Areas Management, Miami, Florida.

Post-hurricane pineland restoration program. Received $3.5M for 5 years; this is final, there will be no more money from the state legislature. Initially after the storm, the pine rocklands appeared to survive the direct physical damage reasonably well, and efforts focused on the crisis of exotic vines invading the hammocks. However, 8 months later rapid mortality of slash pine began occurring, with unexpected abnormally high toll from pine bark beetles (95-100% vs. expected 50-60%). This program was developed to try to preserve the pineland ecosystem, and will cover 37 park sites containing 1,061 acres of pine rockland. [No specific objectives or tasks are presented in this summary.]

Documentation:
Maureen Gregg, Natural Areas Administrator, Park & Recreation Dept., pers. comm.

Dade County Park and Recreation Department. Undated. Post-hurricane pineland restoration program. Executive summary. Metropolitan Dade County Park and Recreation Department, Natural Areas Management, Miami, Florida.

Collection of slash pine seed. In September 1993, a project was started with the Florida Div. of Forestry to collect viable seeds from remaining living pines. Staff from the 2 agencies collected 24 bushels of cones (about 200,000 seeds) from several parks in Dade Co. The seeds are stored in north Florida where state foresters are assessing their viability and propagating them for replanting, hopefully in spring 1995. Seed collection will continue in future years.

Documentation: McHargue, L., and R. Hammer. 1994. Metro Parks' natural areas management. Garden News 49(2):15-16. Fairchild Tropical Garden, Miami, Florida.

Exotic pest plant control survey. Mail survey to determine the statewide status of exotic pest plant invasion into natural areas as it impacts local governments. Intended to obtain input from local governments responsible for managing natural areas or preserves. (Federal and state governments were surveyed directly by DEP.) Information (deadline was 3/18/94) was to be used to develop funding legislation for exotic pest plant control research, removal, and restoration.

Documentation:
Maureen Gregg, Natural Areas Administrator, Park & Recreation Dept., pers. comm.
Don Schmitz, Florida Dept. of Envir. Prot., Tallahassee, pers. comm.
Dade County Park and Recreation Department. Undated. Exotic pest plant control survey instructions. Metropolitan Dade County Park and Recreation Department, Natural Areas Management, Miami, Florida.

Hammock restoration program. Program is restoring 4 of the largest hammocks in Dade Co. (Matheson, Snapper Creek, Deering Estate, and Castellow) following Hurricane Andrew. Goals are to restore native tree canopy, facilitate native seedling recruitment in the understory, and removing exotic species. Over 50 species of exotic pest plants are being treated. Additional funding will be provided by the state for other public forests.

Documentation:
Flynn, L. 1994. Post-hurricane natural areas management: tropical hardwood hammocks. The Palmetto, Summer 1994:16. The Florida Native Plant Society, Orlando, Florida.
Klein, J. Undated. South Dade rockland hammocks. Fact sheet. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.
McHargue, L., and R. Hammer. 1994. Metro Parks' natural areas management. Garden News 49(2):15-16. Fairchild Tropical Garden, Miami, Florida.

Conservation partnership between PRD, The Nature Conservancy, and Fairchild Tropical Garden. Led to development of management plans for many significant publicly owned rockland forests.

Documentation: Dade County Department of Environmental Resources Management. 1993. Endangered pine rockland plant species recovery project. Draft annual report. Dade County Department of Environmental Resources Management, Miami, Florida.

University of Miami/Florida International University.

South Dade planning studies. Design professionals, government officials, members of civic organizations, and residents attended a workshop to create plans for rebuilding the extensive hurricane-damaged area of South Dade Co. Three of the studies proposed were a regional context study, a natural

patterns study, and an urban and agricultural land use study. Some of the priorities identified in the workshop were:

Follow an environmental restoration plan that ensures sustainable balance between natural resources and human needs and desires.

Promote renewal of the natural environment.

- The regional image will be improved by reclamation and protection of wetlands.
- The long-term natural resources of the region must be preserved.
- South Dade residents are the caretakers of the national parks and must protect the environment to ensure the parks' future and the area's economy.
- Address reforestation of the area.
- Establish a greenway network.
- Regain the environmental integrity and aesthetic quality of the landscape.

Water quality and quantity must be protected and controlled to sustain the supply of freshwater to urban, agricultural, and natural systems.

Emphasize rebuilding existing urban areas rather than building anew in peripheral areas.

- Rebuilding should not expand into undeveloped areas.
- Urban growth to the west that is unsympathetic to natural and agricultural systems must be stopped.

Integrate natural systems, consolidate urban patterns, preserve agriculture, and promote the area's natural and historic richness.

Documentation: University of Miami and Florida International University. 1992. The new South Dade planning charrette: from adversity to opportunity. School of Architecture, University of Miami, and School of Design, Florida International University, Miami, Florida.

Florida International University.

Study of *Galactia* complex. Surveys of several sites have been conducted in the Homestead area to search for *G. smallii*.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Dade County Department of Environmental Resources Management. 1993. Endangered pine rockland plant species recovery project. Draft annual report. Dade County Department of Environmental Resources Management, Miami, Florida.

Post-hurricane studies in hammocks, cypress, and pineland.

Documentation: Joe Maguire, Project Supervisor, DERM, pers. comm.

Office of County Manager.

Environmentally Endangered Lands Acquisition Program (EELAP). This program was initiated in 1990 when Dade Co. voters approved a 2-year tax to raise about $90 million to preserve natural lands. Endangered lands are prioritized based on many criteria. A 2/94 list indicates 12 sites, totaling more than 285 acres, have been purchased. The majority of the land is pineland or a combination pineland and hammock. 6 of the pineland sites were priority sites under the state CARL program.

Sites in Dade Co. totaling 48,468 acres were on the Priority A List for acquisition as of 2/94. By far the most ambitious project is the South Dade Wetlands Acquisition Project. The proposed land to be acquired (47,639 acres of freshwater wetlands) is comprised of 2 tracts: North C-111 Wetlands Basin (7,533 acres;

681 parcels; 555 owners; 1992 tax assessed value of $12.7M) and Model Land Basin (40,106 acres; 1303 parcels; 927 owners, including the federal government; 1992 tax assessed value of $35.6M). The Dade Co. EELAP and the SFWMD Save Our Rivers Program are jointly funding the purchase, and a management plan is being completed for this project. The southern 3/4 of the Model Land Basin is one of the most pristine wetland areas outside of ENP. It is comprised of native freshwater wetlands characterized by a sawgrass and tree island mosaic, a significantly large and biologically exceptional area of mangrove forest and coastal wetlands. Occurrence of exotic species is extremely limited. The sheet flow of freshwater across this area into Biscayne Bay is still intact, making the site extremely important for preservation of the South Florida marine system. The northern 1/4 of the basin is impacted by human-induced disturbance, including previous farming, creation of fill roads for canal and powerline access, solid waste dumping, and localized exotic invasion. Much of the area is still sawgrass glades and native forested wetlands that serve as a significant biological and hydrological buffer between agriculture and development and the unstressed wetlands to the south.

14 tracts of tropical hammocks totaling 264 acres are also on the Priority A List for acquisition. The largest of these (60 acres) is the only one of these tracts in North Dade; the rest (ranging from 3.7 to 32.6 acres) are in South Dade. 12 tracts of Miami rockridge pinelands totaling 231 acres (range 9.3 to 39.6) are also proposed. All of these are in South Dade. 3 tracts totaling 145 acres (90, 35, and 20 acres) are on the list as additions to the Tamiami Pineland. The only other project in North Dade is comprised of 5 tracts of primarily mangroves totaling 50 acres in the Oleta River Corridor. The river is linked to Metro-Dade Greynolds Park, which contains the county's third largest wading bird rookery. The only other wetland site is a 45-acre coastal addition proposed for the Deering Estate. 9 of the 12 rockridge pinelands tracts are sites on the state CARL list; 8 of the 14 tropical hammock sites are CARL sites.

The Priority B List contains only 6 tracts totaling 132.5 acres. 3 of the sites are in North Dade: a 37.5-acre mangrove island and 19.2 acres of xeric coastal scrub, an extremely rare habitat in Dade Co. The other 3 sties are in South Dade: a 20-acre hammock and 55.8 acres of pinelands.

Since the 2/94 list, the 39.6-acre Rockdale pineland parcel (a CARL site) was purchased by the state DOT for $11.3M. 2/3 of the land will be repurchased by the county EELAP and Transit Agency. The site is habitat for the endangered deltoid spurge. Also, the county is ready to close on the Spartina wetland north of the Deering Estate and will remove exotics from this marsh.

Documentation:

Burzycki, G. 1994. Letter to C. Goodyear dated February 22, 1994. Metro-Dade Department of Environmental Resources Management, Miami, Florida.

Dade County Department of Environmental Resources Management. Undated. South Dade wetlands vegetation mapping statement of work. Draft. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Dade County Department of Environmental Resources Management. 1992. Save Our Rivers/model land site. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Dade County Department of Environmental Resources Management. 1993. Model lands addition. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Grossenbacher, C., DERM, pers. comm.

Land Trust of Dade County, Trust for Public Land, and Metropolitan Dade County Park and Recreation Department. 1994. Greenways for Dade: An integrated system of linear corridors linking people and places.

Muhs, A. 1994. Tiny, rare wildflower wins right to bloom. March 23, 1994. The Miami Herald, Miami, Florida.

Young, E. 1994. Acquisition Projects: Environmentally Endangered Lands Program, list and map, February 1994. Metro-Dade Environmentally Endangered Lands Program, Office of the County Manager, Miami, Florida.

Young, E. 1994. South Dade Wetlands Acquisition Project: ownership, assessed value, and vulnerability summary, and map. Metro-Dade Environmentally Endangered Lands Program, Office of the County Manager, Miami, Florida.

Metro-Dade Office of Community Development.

Goulds Greenway Trail. Proposal for redevelopment of Goulds neighborhood, emphasizing linear parkland along U.S. 1 and a transit line and anchored by parkland along Black Creek Canal on the north and the proposed Rockridge Pineland Preserve/ Parkland on the south.

Documentation: Alden, C.A. Undated. Greenway trail proposal, Goulds neighborhood redevelopment concept, Miami, Florida. Allen & Associates, P.A., prepared for Metro-Dade Office of Community Development.

Florida Department of Environmental Protection, Division of Recreation and Parks.

Restoration of Bill Baggs Cape Florida State Recreation Area. The park includes about 400 acres of uplands and 350 acres of submerged land and tidal wetlands, with only 27 acres supporting natural plant communities. The remaining uplands were either developed or covered with fill and infested with Australian pines and 29 other invasive exotic plants. On 8/24/92 Hurricane Andrew devastated the park, leveling most of the pines and leaving the park inaccessible to the public. After clearing of debris, an area equal to 302 football fields was left treeless. Eradication of exotics had been a goal of the park's resource managers for many years, but the scale of this problem - the infestation and its sudden destruction - presented a resource management problem never before encountered. As with all Florida state parks, the primary goal is to restore the original natural processes while providing compatible public recreation opportunities; this includes returning undeveloped areas of state parks to ecological conditions that would exist if Europeans had not colonized Florida, or as close as possible considering the drastic changes in hydrology and topography at Cape Florida from fill operations. Recommended immediate actions for Cape Florida included initiating exotic plant control as soon as possible to prevent exotics from germinating from seed and resprouting from stems and roots, constructing and nursery facility to begin propagating existing native plants as soon as possible, and developing an ecological restoration plan. The restoration may taken 5-10 years just to initiate; 400 acres of persistent exotics (e.g., Australian pine, Burma reed, castor bean, papaya, Brazilian pepper, day jasmine, lather leaf) will have to be controlled, while an estimated 1-2 million native plants are acquired, planted, and maintained. The program will require detailed studies of soil chemistry, hydrology, salinity, and quantitative vegetation analyses of comparable pristine areas. The area of remnant natural maritime hammock, coastal strand, and beach dune communities will be protected from disturbance to allow natural restorative processes to occur. The native communities and ecotones, including marshes and mangroves, that existed prior to 1926 will be re-established in large restoration areas. In intensive public use areas, landscapes will use culturally important plants and native species indigenous to historic upland communities. A specific example of landscape restoration is the plan to redesign failed sections of the seawall and replant with mangroves. DERM will re-establish mangroves in the northwest portion of the park. The overall plant restoration process is includes establishing test wells to determine hydrology, constructing a permanent field grid system, and establishing experimental planting plot to determine effects of mulch, watering, etc.

The following listed plants are found in the park: beach star, burrowing four o'clock (beach peanut), inkberry, cootie, verbena, silver palm, and beach jacquemontia. Prickly-ash is rare in Dade, Broward, and Palm Beach counties.

Documentation:
Huck, R.B. 1993. Restoration initiative for Cape Florida State Recreation Area following Hurricane Andrew. Draft. Florida Department of Environmental Protection, Division of Recreation and Parks, Tallahassee.
Florida Department of Environmental Protection, Division of Recreation and Parks. 1993. Bill Baggs Cape Florida State Recreation Area hurricane recovery and restoration plan. As approved by Governor and Cabinet July 21, 1993. Florida Department of Environmental Protection, Division of Recreation and Parks, Tallahassee.
Schroeder, P. 1994. Plant restoration plan for Cape Florida SRA. Draft. Florida Department of Environmental Protection, Division of Recreation and Parks, Bill Baggs Cape Florida SRA, Key Biscayne, Florida.

South Florida Water Management District.

Surface Water Improvement and Management (SWIM) Program for Biscayne Bay. This updated 1994 planning document replaces the 1988 SWIM plan. It reviews progress on the original recommendations and recommends revised goals, objectives and strategies for the next 3 years. Since 1988, SFWMD has participated in 50 major projects through the SWIM Program, many of these in cooperation with Dade Co. DERM. These projects included research, monitoring, restoration, and education. Many habitat restoration efforts by Dade Co. and local municipalities have been supported by SWIM funds, including mangrove, freshwater wetland, and spoil island projects. Many of these have been discussed above in the section on Dade Co. DERM projects. Proposed restoration projects include an historical landscape analysis of the C-111 basin to quantify relationship between vegetation and hydrologic conditions to explain past and future effects of water management; posting of shoal warning signs to better mark shallow areas to prevent seagrass and hardbottom community damage; and restoration of the Bulk Carrier Site wetland restoration in South Dade. Based on recommendations from Dade Co., NPS, USFWS, other agencies and local governments, SFWMD determined high priority areas for preservation: the 14 mangrove areas in Biscayne Bay identified in the Dade Comprehensive Plan coastal element; upland areas necessary to protect BNP from effects of groundwater seepage and runoff; and areas identified in the Southwest Biscayne Bay ADID study.

Documentation: Alleman, R., D. Black, S. DuToit, S. Formati, C. Gove, and L. Gulick. 1994. An update of the Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. Draft planning document, technical supporting document, and appendices. Lower East Coast Planning Division, South Florida Water Management District, West Palm Beach, Florida.

Land use mapping. Has related land use planning to native vegetation distribution.

Documentation: Tom Singleton, SFWMD, Dade Co. representative, pers. comm.

Land Trust of Dade County, Trust for Public Land, and Metropolitan Dade County Park and Recreation Department.

Greenways for Dade. In response to demand for open space and recreational land, Dade Co. began in 1969 a number of land use studies regarding open space corridors. These continued into the mid-1970s, but resulted in only 3 small projects totaling 6 miles in length. Intensive new efforts got underway in 1993 with planning sessions to guide rebuilding South Dade after Hurricane Andrew. A task force recommended a series of linear corridors and greenways to provide routes wildlife movement as well as trails for pedestrians, bicycles, etc. to link the agricultural communities, parks, natural areas, and public places in the region bounded by Cutler Ridge on the north, Biscayne Bay on the east, and Everglades National Park on the west and south. The South Dade greenway is one link in what is to be countywide network of open

space, wildlife, and human corridors along canals, rivers (Miami, Oleta), utility easements, railroad rights-of-way, Metrorail corridors, beach and bay shoreline, and bicycle and pedestrian paths.

Documentation:
Land Trust of Dade County, Trust for Public Land, and Metropolitan Dade County Park and Recreation Department. 1994. Greenways for Dade: An integrated system of linear corridors linking people and places.
University of Miami School of Architecture. Undated. The new South Dade planning charrette: From adversity to opportunity.

City of Miami Planning Department.

Virginia Key Master Plan. Plan presents approach to developing the barrier island for recreational uses, while ensuring environmentally sensitive areas (tidal flats, mangrove tidal marshes, beach/dunes, and coastal hardwood hammocks) remain undisturbed and undeveloped, restored when necessary, and protected from inappropriate public activity.

Documentation: City of Miami Planning Department. 1987. Virginia Key Master Plan. City of Miami Planning Department, Miami, Florida.

Florida Game and Fresh Water Fish Commission, Everglades Region, West Palm Beach, Florida.

Virginia Key Critical Wildlife Area. 400 acres of shallow tidal flats and mangrove forests on the west side of the island were designated as a Critical Wildlife Area, with the cooperation of the City of Miami, Tropical Audubon Society, The Sierra Club Miami Group, and other conservationists. The area was established mainly for the more than 25 species of birds that spend the winter resting and feeding in this critical habitat in the shadow of the Miami skyline. The area is closed to entry between August 1 and May 1 each year. The submerged land portion is encompassed in the "No Entry" zone recently established for manatee protection on the northwest side of Virginia Key.

Documentation:
Florida Game and Fresh Water Fish Commission. Undated. Did you know? There is a wildlife treasure in the heart of Miami. Pamphlet. Florida Game and Fresh Water Fish Commission, Everglades Region, West Palm Beach, Florida.
Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

Redland Conservancy.

Greenway Network Plan for South Dade County. The Redland Conservancy has received $100,000 from the Metro-Dade Hurricane Andrew Trust Fund and the Elizabeth Ordway Dunn Foundation to prepare this first greenway plan for Dade Co. When complete the network will extend from Miami International Airport south to link with trails in the Florida Keys, Biscayne National Park, and Everglades National Park. Planning charrette will be held during summer 1994 with the final plan completed by October 1994.

Documentation: 1000 Friends of Florida/The Conservation Fund. 1994. Greenways for Dade. Florida Greenways 2(2):4.

Tropical Audubon Society/The Junior League of Miami, Inc.

Xeriscape landscape project. The gardens on a 3-acre site surrounding the Doc Thomas House were restored after being virtually untended for nearly 40 years. The grounds sit atop the Miami rockridge and were part of the Dade Co. pine rockland and hardwood hammock forests. Intrusive and poisonous exotics were removed. Some exotics were retained for aesthetic or historical significance. When the site was cleared of unwanted plants, pine rockland plants that had been dormant for many years started growing again. Reforestation used only native species, selected on the basis of water conservation. The gardens contain a pineland with young slash pine, saw palmetto, and wildflowers (some endangered); a hammock typical of South Miami; and a second hammock characteristic of the Brickell Hammock that once extended from the Miami River to Coconut Grove. The project is intended to serve as a model and an inspiration to gardeners. Free public tours of the site are conducted.

Documentation: Link, E.J., and C. Lippincott (eds.). Undated. The Doc Thomas house and grounds, an approach to xeriscape. Brochure. Tropical Audubon Society/The Junior League of Miami, Inc.

Florida Department of Transportation, District 6.

Gratigny Expressway Wetlands project. With assistance from a native plant grower and an ecological restoration consulting firm, this project converted a high-maintenance grass interchange with drainage ditches, embankments, bridges, roads, and one royal palm into a 6.5-acre wetland with 15 acres of associated upland. Substantial regrading of soil elevations was necessary to achieve suitable wetland conditions and pollution retardation. This effort received the top landscape award for 1994 from the Florida Native Plant Society.

Documentation:
Florida Native Plant Society. 1994. Landscape award winners. The Palmetto, Summer 1994:14-15. The Florida Native Plant Society, Orlando, Florida.
Florida Department of Transportation. 1990. State Road No. 924 (Gratigny Parkway) landscaping plans. Florida Department of Transportation, District 6, Miami, Florida.

Mangrove planting in Oleta River State Recreation Area.
[waiting for information]

Documentation: Christie Pritchard, FDOT, District 6, pers. comm.

Mitigation for U.S. 1 project. The widening of U.S. 1 from the mainland to Key Largo will require wetlands and seagrass mitigation.
[waiting for information]

Documentation: Christie Pritchard, FDOT, District 6, pers. comm.

REGION

U.S. Environmental Protection Agency.

Advance Identification of Wetlands Program (ADID). ADID is a planning process authorized by Section 404 regulations. EPA (in cooperation with COE, state, and other resource agencies) determine the ADID study area and assembles a team to conduct a field study on the natural characteristics and functions of the study area wetlands. The wetlands are mapped and the information collected is evaluated to

determine which wetlands are of high ecological value and should be protected from dredge and fill activities and are of low value and might serve as dredge disposal sites. Preliminary findings are compiled in a Technical Summary Document, provided to review agencies and to the public for comment. Determinations are informational and nonregulatory. ADID projects in Subregion 9 are the S.W. Biscayne Bay ADID and the West Broward County ADID (both described above).

Documentation:
U.S. Environmental Protection Agency. 1992. Advance Identification of Wetlands Program. Fact sheet. United States Environmental Protection Agency, Region 4, Atlanta, Georgia.
U.S. Environmental Protection Agency. 1994a. South Florida wetland planning activities, advance identification (ADID) wetland planning projects. Wetlands Planning Unit, United States Environmental Protection Agency, Region 4, Atlanta, Georgia.

Florida Game and Fresh Water Fish Commission, Nongame Wildlife Section.

Coastal Wildlife Conservation Plan. Long-range planning to conserve vulnerable coastal wildlife and their habitat involved identifying research tasks needed for conservation and management. Many of these planned projects on shorebirds, neotropical migrants, wading birds, and tidal swamp songbirds apply to habitat present in Subregion 9:

Development of guidelines for protection of shorebird wintering areas.
Development of a shorebird nesting area protection network.
Management of shorebird nesting sites on public lands.
Predator regulation at shorebird nesting sites.
Development-related guidelines for protection of shorebird nesting habitat.
Cooperation with other agencies to review development plans in migrant bird concentration areas.
Restoration of coastal upland habitats to support neotropical migrant birds.
Development of a coastal wading bird nesting area protection network.
Development of guidelines for protection of colonial wading bird colonies.
Compilation of records of important tidal swamp songbird habitat areas.
Monitoring of tidal swamp songbird populations in selected key habitat areas.
Initiate cooperation with other agencies to review mangrove clearing permits.
Mangrove restoration and expansion program.

Documentation: Millsap, B.A., J.A. Gore, and J.A. Feiertag. 1991. Coastal wildlife conservation plan. Annual performance report, 1 July 1990 - 1 July 1991. Nongame Wildlife Section, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Florida Department of Environmental Protection.

State plan to control exotic pest plants. Project obtained input from each county to establish a state-wide program to control according to ecosystem management principles. Information was to be used to develop funding legislation for exotic pest plant control research, removal, and restoration. A mail survey gathered information on the statewide status of exotic pest plant invasion into natural areas on public lands and the research and funding needed to control them.

Documentation:
Don Schmitz, Florida Dept. of Envir. Prot., Tallahassee, pers. comm.

University of Florida.

Study of wildlife diversity. The FG&FWFC is providing funds through the Nongame Wildlife Program for a 5-year study of relationships between human population growth and wildlife species diversity in hardwood hammock fragments. (Subreg. 9?)

Documentation: Florida Game and Fresh Water Fish Commission. 1993. Nongame Wildlife Program contracted projects that have been funded by Florida Game and Fresh Water Fish Commission as of September 15, 1993. Table. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

The Nature Conservancy.

Control of melaleuca. The FG&FWFC is providing funds through the Nongame Wildlife Program for a 3-year study on the use of fire in containment and potential control of melaleuca in South Florida wetland habitats. (Subreg. 9?)

Documentation: Florida Game and Fresh Water Fish Commission. 1993. Nongame Wildlife Program contracted projects that have been funded by Florida Game and Fresh Water Fish Commission as of September 15, 1993. Table. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Dade County Department of Environmental Resources Management.

Genetics profile of South Florida slash pine done under contract to U.Ga. (Dr. James Hamrick) with DERM funds. The spatial separation of the forests plus the differing edaphic conditions on which they grow provide concern that genetic differentiation may exist throughout the region. Genetic background data will help determine appropriate slash pine forest sites as seed donor sites. Completing a genetic profile may identify locations with unique or particular seed collection needs for future restoration. DERM coordinates the collection of buds or needles with Florida DOF from 48 trees at each of 8 sites in pine rocklands and 8 sites in sandy pinelands. The sites are from Lee, Hendry, and Palm Beach counties south to the Lower Keys. Allozyme testing is conducted to answer: Is there genetic differentiation between forests growing on oolitic limestone and those in sand? Is there evidence that the disjunct forests are reproductively isolated or genetically different? How does the genetic profile of the Miami Rock Ridge sites compare to profiles of other rockland sites? This project was a direct recommendation in the above restoration plan. Contract to be completed about mid-May.

Documentation:
Joe Maguire, Project Supervisor, DERM, pers. comm.
Dade County Department of Environmental Resources Management. 1994. Dade County pine rockland restoration plan following Hurricane Andrew. Draft document. Dade County Department of Environmental Resources Management, Miami, Florida.
Dade County Department of Environmental Resources Management. Undated. Genetic profile of South Florida slash pine. Draft project description. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Florida Power and Light Company.

Mitigation banking program.
[waiting for information]

Documentation: Bob Kessler, FP&L, pers. comm.

Florida Greenways Program. 1000 Friends of Florida/The Conservation Fund.

Mapping of greenways. To be completed by summer 1994.

Documentation: Kent Wimmer, Community Planner, 1000 FOF, pers. comm.

State of Florida

Conservation and Recreational Lands (CARL) Program. State program that buys native ecosystems and sensitive areas; prioritizes lands for acquisition. Funding source is a severance tax on phosphate, oil and gas, and minerals.

Documentation: Gleason, P.J. 1984. Introduction. Pages viii-xxv *in* P.J. Gleason, editor. Environments of South Florida, present and past II. Miami Geological Society, Coral Gables, Florida.

U.S. Man and the Biosphere Program, Human Dominated Systems Directorate.

Encroachment and land use change in South Florida. Little is known about the actual effectiveness of biosphere preserves, especially when areas surrounding reserves have seen significant human population growth. Research is being conducted to evaluate the concept of sustainability as related to reserves such as the Everglades. GIS analyses were done to produce encroachment maps showing the change in groundcover from natural areas (wetlands, non-wetlands) to human use (e.g., agriculture). Data sources were U.S. census, USGS, and SFWMD. Many areas on the western edge of the Lower East Coast urban area showed more intense encroachment than would be expected from census data.

Documentation: Walker, R.T., and W.D. Solecki. 1994. Encroachment and land use change in biosphere reserve regions. HDS-GIS Specialty Group, Department of Geography, Florida State University, Tallahassee. Paper presented at the Human Dominated System Directorate of U.S. MAB Program Workshop, January 5-7, 1994, Miami, Florida.

HDS-GIS data dictionary. A listing, including data descriptions, was compiled of the GIS databases available for the Everglades Biosphere Reserve and South Florida.

Documentation: Zapolsky, S. 1993. Ecological Sustainability and Human Institutions Project HDS-GIS data dictionary. Department of Geography, Florida State University, Tallahassee, Florida.

BIOTA/PROTECTED SPECIES

PALM BEACH COUNTY

Town of Palm Beach.

Mid-Town PEP reef sea turtle monitoring study. The period of 4/19/93 - 10/5/93 was the first season of a 3-year survey of nesting success following the installation of an experimental prefabricated erosion prevention (PEP) concrete and steel reef along 4,000 feet of beach at Palm Beach. Nesting was observed from May through August with all activity from loggerhead turtles. Green and leatherback turtles are also known to nest on beaches of Palm Beach, but in low numbers. This will be the first systematic study of sea turtle nesting in the town of Palm Beach.

Documentation: Town of Palm Beach. 1993. Mid-Town PEP reef sea turtle monitoring study, April 19 - October 5, 1993. Town of Palm Beach, Palm Beach, Florida.

Florida International University.

Erosion prevention modules monitoring study. In 1987, a 1000-foot line of erosion prevention modules was installed in 8 ft of water parallel to the beach in front of the Dupont Estate in Palm Beach Co. During the 1988 and 1989 turtle nesting seasons monitoring was conducted to determine the impact of these concrete structures on nesting. Results indicated the modules did not interfere with nesting.

Documentation: Fletemeyer, J.R. 1991. The nesting imperative: a study of conflicts between humans and sea turtles on Southeast Florida beaches. Ed.D. dissertation. Florida International University, Miami, Florida.

City of Boca Raton.

Sea turtle nesting survey. Since 1979, the City has conducted surveys for nesting activity at the public beach.

Documentation: Harris, B.A., W.J. Conley, and J.A. Huff. 1984. The status of Florida's nesting sea turtle populations from 1979 through 1983. Florida Department of Natural Resources, St. Petersburg, Florida.

Sea Turtle Nest Protection and Relocation Program. Extensive turtle nest relocation was conducted in 1988 because of severe erosion problems, as well as the North Beach Nourishment Project. A study on hatching and emergence success was conducted by Florida Atlantic University at 4 beach sites in Boca Raton, Florida, during the 1990 nesting season subsequent to the renourishment project. A 3-year follow-up study on the 1985 South Beach Nourishment Project showed improved nesting densities and success.

Documentation:
Broadwell, A.L. 1992. Effects of beach renourishment on the survival of loggerhead sea turtle nests. Pages 21-23 *in* M. Salmon and J. Wyneken, editors. Proceedings of the eleventh annual workshop on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-302. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.
Wolf, R.E. 1989. Boca Raton sea turtle protection program (1988) in conjunction with the North Beach Nourishment Project. Page 191 *in* S.A. Eckert, K.L. Eckert, and T.H. Richardson, editors. Proceedings

of the ninth annual workshop on sea turtle conservation and biology. NOAA Technical Memorandum NMFS-SEFSC-232. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Florida Atlantic University.

Sea turtle nesting patterns. A 1989-92 survey of nesting patterns of loggerhead turtles on a Boca Raton beach showed that nesting density was strongly correlated with elevation of objects (trees, buildings) behind the beach.

Documentation: Salmon, M., M. Tolbert, M. Goff. 1994. Nesting patterns of loggerhead sea turtles on an urban beach (Boca Raton, Florida). Page 156 *in* B.A. Schroeder and B.E. Witherington, editors. Proceedings of the thirteenth annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-341. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Hatchling misorientation. Experiments conducted on a Boca Raton beach showed cases of misorientation caused by anthropogenic light sources were common. The high incidence at Boca Raton was caused by both the presence of the light sources and the presence of background silhouettes (outlines of high buildings) with many light gaps. Masking the spaces between buildings with tall trees, dunes, or other barriers would help correct the problem.

Documentation: Reiners, R., M. Salmon, and C. Lavin. 1994. Hatchling misorientation on an urban beach (Boca Raton, Florida). Page 146 *in* B.A. Schroeder and B.E. Witherington, editors. Proceedings of the thirteenth annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-341. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

University of Florida, Archie Carr Center for Sea Turtle Research.

Hatchling misorientation. Experiments conducted on Delray Beach showed that not only were artificial lights which could be seen directly from the beach responsible for disorientation but also lights that could not be seen directly from the beach (light reflected from buildings and vegetation or scattered by clouds and mist).

Documentation: Witherington, B.E. 1990. Low pressure sodium vapor lighting and hatchling orientation. Unpublished report submitted to City of Delray Beach. As referenced in Fletemeyer 1991.

Broward County Audubon Society

Monitoring and sampling of stranded turtles. Since 1986, a stranding hotline, first sponsored by Broward County Audubon Society has gathered reports in Broward Co. It was expanded to Palm Beach Co. in 1990. Necropsies have been conducted and stomach samples collected. Most of the juvenile green turtles contained a mix of algae and seagrasses. The ingested algae were representative of the offshore flora proximate to the stranding location. The presence of Rhodophytic algae plus sighting of turtles feeding upon these plants especially illustrates the importance of the hardbottom areas of Broward and Palm Beach counties.

Documentation:
Wershoven, R.W., and J.L. Wershoven. 1992. Stomach content analysis of stranded juvenile and adult green turtles in Broward and Palm Beach counties, Florida. Pages 124-126 *in* M. Salmon and J. Wyneken, editors. Proceedings of the eleventh annual workshop on sea turtle biology and conservation. NOAA

Technical Memorandum NMFS-SEFSC-302. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Florida Atlantic University.

Survey of natural resources on FAU campus. An inventory of resources in the natural and man-made areas of the campus was conducted so these features might be considered in future campus development projects. Several areas were recommended for preservation as study areas (e.g., as pine woods succession or scrub ridge succession) or for refuges for protected native species. Gopher tortoises were common in more protected areas of the campus. The population of burrowing owls had declined to an estimated 4 active burrows in 1986. There were 18 in 1971 when the campus was designated a National Audubon Sanctuary for this species. Projected causes of the decline were human encroachment; introduction of trees to the landscape; predation by feral cats, dogs, or giant marine toads; or pesticide poisoning.

Documentation: Burch, J.N., and G.A. Marsh. 1987. Survey of natural resources within the limits of the Florida Atlantic University campus. Joint Center for Environmental and Urban Problems, Florida Atlantic University, Boca Raton, Florida.

Florida Game and Fresh Water Fish Commission, Bureau of Nongame Wildlife, Division of Wildlife.

Southeastern beach mouse survey. 2 sites in Palm Beach Co. (MacArthur Beach State Park and Manalapan beach) were included in a 1988-89 trap survey of the 5 best examples of remaining each dune habitat from Brevard Co. south through Palm Beach Co. No evidence of beach mouse populations was found in Palm Beach Co., and it is unlikely the mouse occurs south of St. Lucie Co. At the time of the survey, a private landowner on the beach at Manalapan, just north of Boynton Beach, was completing a major restoration project of the dune system, including a low foredune vegetated with sea oats, other native graminoids, and beach shrubs. When established, this habitat could possibly support a mouse population.

Documentation: Robson, M. 1989a. Southeastern beach mouse survey. Final performance report. Florida Game and Fresh Water Fish Commission. Bureau of Nongame Wildlife, Division of Wildlife. Tallahassee.

U.S. Fish and Wildlife Service.

Breeding bird survey. This national survey collected information on distributions, local densities, and population trends of breeding birds from 1969-1983. One of the Florida survey routes was in Boca Raton, Palm Beach County, and was covered the entire 15 years.

Documentation: Cox, J. 1987. The breeding bird survey in Florida: 1969-1983. Florida Field Naturalist 15:29-44.

BROWARD COUNTY

Broward County Department of Natural Resource Protection, Biological Resources Division.

Sea turtle conservation program. A major conservation effort was started in 1975 to mitigate some of the problems which threaten sea turtle survival in Broward Co. Funded since 1978, this program has conducted daily surveys during turtle nesting season on Broward beaches since 1981 through contracts to Nova University. The loggerhead turtle is the primary nesting species; green and leatherback turtles also nest on the beaches. The project includes relocating eggs from nests endangered by natural process or

human activities, surveying turtle nesting patterns and the effects of beach renourishment, assessing the success of recruitment, disposing of turtle carcasses, and educating the public about turtle conservation. The surveys are normally conducted from mid-April to mid-September and include the entire shoreline of Broward Co. (Hillsboro-Deerfield beach, Pompano beach, Fort Lauderdale beach, John U. Lloyd State Recreation Area beach (conducted by park personnel), and Hollywood-Hallandale beach). Since 1975, many research studies have been conducted in concert with the basic nesting survey. These include studies on pen rearing and head starting, tagging, strandings, hatchling incubation success, artificial incubation methods, sex-temperature determination, hatchling light orientation and dispersal, juvenile behavior and dispersal, and analysis of heavy metals and PCBs in eggs. There were many cooperators in these studies besides Nova University and Broward Co., including Oceanworld; Theater of the Sea; Florida Power & Light; the cities of Fort Lauderdale, Hollywood, and Pompano Beach; and Palm Beach Co.

Documentation:

Burney, C., and W. Margolis. 1993. Sea Turtle Conservation Program, Broward County, Florida, 1993 report. Technical Report 93-10. Broward County Department of Natural Resource Protection, Biological Resources Division, Fort Lauderdale, Florida.

Burney, C., and C. Mattison. 1993. Sea Turtle Conservation Program, Broward County, Florida, 1992 report. Technical Report 93-1. Broward County Department of Natural Resource Protection, Biological Resources Division, Fort Lauderdale, Florida.

Burney, C., and C. Mattison. Undated. Sea Turtle Conservation Project, Broward County, Florida, 1991 report. Broward County Office of Natural Resource Protection, Erosion Prevention District, Fort Lauderdale, Florida.

Burney, C.M., C. Mattison, and L. Fisher. 1990. The relationship of loggerhead nesting patterns and moon phase in Broward County, Florida. Pages 161-164 *in* T.H. Richardson, J.I. Richardson, M. Donnelly, editors. Proceedings of the tenth annual workshop on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFC-278. USDOC/NOAA/NMFS Southeast Fisheries Center, Miami, Florida.

Fletemeyer, J.R. Undated. Sea Turtle Conservation Project, Broward County, Florida, 1986 report. Broward County Erosion Prevention District, Environmental Quality Control Board, Fort Lauderdale, Florida.

Fletemeyer, J. 1983. 1983 report, sea turtle monitoring project. Cooperative Sea Turtle Monitoring Program, Nova University and Broward County Environmental Quality Control Board.

Fletemeyer, J. 1984. 1984 report, sea turtle monitoring projects. Cooperative Sea Turtle Monitoring Program, Nova University and Broward County Environmental Quality Control Board.

Mattison, C., C.M. Burney, and L. Fisher. 1990. Sea turtle nesting and hatching success in Broward County, Florida, 1989. Pages 165-168 *in* T.H. Richardson, J.I. Richardson, M. Donnelly, editors. Proceedings of the tenth annual workshop on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFC-278. USDOC/NOAA/NMFS Southeast Fisheries Center, Miami, Florida.

Mattison, C., C.M. Burney, and L. Fisher. 1994. Trends in the spatial distribution of sea turtle activity on an urban beach (1981-1992). Pages 102-104 *in* B.A. Schroeder and B.E. Witherington, editors. Proceedings of the thirteenth annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-341. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Broward County Audubon Society.

Assessment of juvenile green turtles in Broward County. Since 1986, assessment of the population of juvenile green turtles and its foraging and resting habitat has been conducted in Broward Co. The presence of substantial numbers of green turtles observed by divers feeding and resting indicated the reef areas of Broward serve as important developmental habitat. Juveniles utilize a large expanse of hardbottom reef, which provides adequate forage and hydrographical relief. Potential threats are recreational diving on the

reefs, boating activities, and frequent freshwater discharges from water management canals during heavy rainfall. The discharges may be linked to algae blooms that out-compete preferred algal forage. Beach renourishment projects should be monitored to prevent impact on algae and seagrass food sources.

Documentation:
Wershoven, J.L., and R.W. Wershoven. 1992. Juvenile green turtles in their nearshore habitat of Broward County, Florida: a five year review. Pages 121-123 *in* M. Salmon and J. Wyneken, editors. Proceedings of the eleventh annual workshop on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-302. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.
Wershoven, R.W., and J.L. Wershoven. 1989. Pages 185-187 *in* S.A. Eckert, K.L. Eckert, and T.H. Richardson, editors. Proceedings of the ninth annual workshop on sea turtle conservation and biology. NOAA Technical Memorandum NMFS-SEFSC-232. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Monitoring and sampling of stranded turtles. Since 1986, a stranding hotline, first sponsored by Broward County Audubon Society has gathered reports in Broward Co. It was expanded to Palm Beach Co. in 1990. Necropsies have been conducted and stomach samples collected. Most of the juvenile green turtles contained a mix of algae and seagrasses. The ingested algae were representative of the offshore flora proximate to the stranding location. The presence of Rhodophytic algae plus sighting of turtles feeding upon these plants especially illustrates the importance of the hardbottom areas of Broward and Palm Beach counties.

Documentation:
Wershoven, R.W., and J.L. Wershoven. 1992. Stomach content analysis of stranded juvenile and adult green turtles in Broward and Palm Beach counties, Florida. Pages 124-126 *in* M. Salmon and J. Wyneken, editors. Proceedings of the eleventh annual workshop on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-302. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

DADE COUNTY

Dade County Department of Environmental Resources Management.

Manatee distribution surveys. Aerial surveys have been conducted since 12/89, either monthly or biweekly year-round. The FDNR conducted surveys from 12/87 - 3/90, usually biweekly. These data plus public sightings are entered into a GIS.

Documentation:
Keven Mayo, DERM, pers. comm.
Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

Manatee mortality database. Data on manatee mortality have been recorded since 1974. Carcasses are recovered, necropsies performed, and the cause of death determined.

Documentation: Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

Manatee protection plan. Dade Co. implements this plan to: reduce manatee mortalities and injuries, protect manatee habitat, minimize manatee harassment, increase public awareness of the need to protect manatees and their environment, and monitor status of manatee populations and their habitats.

Documentation: Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

South Florida Water Management District.

Manatee protection at flood control structures. Crushing and/or drowning in flood gates is the largest known cause of manatee mortality in Dade Co. 42 deaths have been documented at 7 different structures operated by the SFWMD between 1974 and 1993. The SFWMD has researched several alterations of the structure and operation of the gates, which have not been completely successful. The most recent modification was to be installed at the Snake Creek salinity control structure in spring 1994.

Documentation: Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

Florida Power and Light Co.

Monitoring of American crocodile at Turkey Point Nuclear Power Plant. The power plant site at Turkey Point is ideal habitat with its 168 miles of saltwater cooling canals, abundant food, isolation from people, and secure nesting berms along the canals. FP&L's program began in 1978 when the finding of a dead hatchling showed breeding was occurring. In 1980, 2 nest sites were found on berms. In 1987 the population totaled 20-30 individuals; 10% of Florida's crocodile hatchlings were produced here. FP&L protects the crocodiles with a management plan that ensures activities such as maintenance do not interfere with the crocodiles. A monitoring program is overseen by Frank Mazzotti of the Univ. of Florida. In 1992, there were 12 nests and 155 hatchlings. In 1993, there were 11 nests and 181 hatchlings. All hatchlings are marked with notches in their tail scutes by biologists.

Documentation:
Gaby, R., M.P. McMahon, F.J. Mazzotti, W.N. Gillies, and J.R. Wilcox. 1985. Ecology of a population of *Crocodylus acutus* at a power plant site in Florida. Journal of Herpetology 19:189-198.
Garlock, M. 1994. Crocodile comeback at Turkey Point. Florida Naturalist 67(1):13-15.
Van Meter, V.B. 1987. Florida's alligators and crocodiles. Prepared for Florida Power & Light Company, Miami, Florida.

Florida International University.

Sea turtle nesting survey. Aerial surveys conducted over Dade County beaches indicated nesting increased from south to north.

Documentation: Fletemeyer, J.R. 1991. The nesting imperative: a study of conflicts between humans and sea turtles on Southeast Florida beaches. Ed.D. dissertation. Florida International University, Miami, Florida.

Florida Department of Environmental Protection.

Sea turtle nesting survey at Cape Florida. The beaches of Bill Baggs Cape Florida State Recreation Area on Key Biscayne have been monitored for turtle nesting since 1980.

Documentation:
Conley, W.J., and B.A. Hoffman. 1987. Nesting activity of sea turtles in Florida, 1979-1985. Florida Scientist 50:201-210.
Harris, B.A., W.J. Conley, and J.A. Huff. 1984. The status of Florida's nesting sea turtle populations from 1979 through 1983. Florida Department of Natural Resources, St. Petersburg, Florida.

Dade County Park and Recreation Department.

Sea turtle nesting survey. Since 1980, the beaches of the Miami area have been surveyed for nesting activity as part of the FDEP index survey. The area patrolled extends approximately 14 miles, from Government Cut at the tip of Miami Beach north to Golden Beach, almost at the Broward Co. line. Each nest found is relocated to a hatchery.

Documentation:
Bill Ahern, DCPRD, Beach Operations, pers. comm.
Harris, B.A., W.J. Conley, and J.A. Huff. 1984. The status of Florida's nesting sea turtle populations from 1979 through 1983. Florida Department of Natural Resources, St. Petersburg, Florida.

Sea turtle nesting survey at Crandon Park. The beaches of Crandon Park have been patrolled for nests since 1981. Eggs are collected from the nests to protect them from beach equipment, poaching, and predators. The eggs are taken to a hatchery in the park, and hatchlings are released from park beaches. Until 1993, the survey was conducted by Tropical Audubon Society.

Documentation:
Dade County Park and Recreation Department. 1991. Crandon Park, natural areas protection plan. Metro-Dade County Park and Recreation Department, The Nature Conservancy, and Fairchild Tropical Garden, Miami, Florida.
Harris, B.A., W.J. Conley, and J.A. Huff. 1984. The status of Florida's nesting sea turtle populations from 1979 through 1983. Florida Department of Natural Resources, St. Petersburg, Florida.

National Marine Fisheries Service, Southeast Fisheries Science Center.

Sea turtle nesting survey on Virginia Key. Nest counts have been conducted since 1990 on the beach of Virginia Key.

Documentation: Wendy Teas, SEFSC, pers. comm.

University of Miami/Florida Atlantic University.

Post-hurricane nesting survival. Surveys were conducted after Hurricane Andrew in 8/92. Egg mortality due to storm surge was 100% in nests on Key Biscayne and Virginia Key, the beaches closest to the storm's eye. In areas further away, delayed mortality was caused by changed beach topography. On Fisher Island, just north of Virginia Key, 8 nests that had been relocated from Jupiter in a beach renourishment study suffered heavy mortality from a combination of storm surge, later torrential rains, and heavy accumulation of sand on the nests.

Documentation:
Leone-Kabler, S., S.L. Shaw, P. Lutz. 1994. Effects of Hurricane Andrew on sea turtle nesting beaches of South Florida. Page 247 *in* B.A. Schroeder and B.E. Witherington, editors. Proceedings of the thirteenth annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-341. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.
Shaw, S.L., A.A. Schulman, and P. Lutz. 1994. The effect of Hurricane Andrew on a monitored *Caretta caretta* nesting beach. Pages 170-171 *in* B.A. Schroeder and B.E. Witherington, editors. Proceedings of the thirteenth annual symposium on sea turtle biology and conservation. NOAA Technical Memorandum NMFS-SEFSC-341. USDOC/NOAA/NMFS Southeast Fisheries Science Center, Miami, Florida.

Topical Audubon Society.

Tern Project. The TAS initiated a project in South Florida to identify actual and potential nesting sites of the least tern, a state threatened species, and to implement measures to monitor, protect, and enhance these sites. The first phase of the project is designation, in cooperation with Dade Co. Park and Recreation Dept., of a potential nesting site on the north side of the Crandon Park marina as a protected area. Terns were observed attempting to nest here, but they abandoned the site because of disturbance by humans and their pets. A chainlink fence was erected around the site in May 1993 to deter feral cats and reduce pedestrian traffic, and volunteers have removed invasive vegetation and added coarse sand and shell to the site.

Documentation: Goodwin, J. 1994. The tern project. Tropical Audubon Bulletin, May 1994:1-2.

University of Florida/U.S. Fish & Wildlife Service.

Endangered snail rescue effort. Only a few days after Hurricane Andrew devastated the hammock habitat at Monkey Jungle south of Miami on 8/24/92, an effort was initiated by USFWS and the University of Florida to rescue the snails, including many varieties and forms that are now extinct in the Keys, that were now exposed to direct sunlight and house them until the hammock could recover.

Documentation: Emmel, T.C. 1992. Mother Nature reeks havoc on endangered habitats. The Florida Naturalist 65(3):12-13,15,22.

Fairchild Tropical Garden.

Endangered plant propagation. The Garden is carrying out garden propagation of plants for the Center for Plant Conservation. Among those being propagated is the crenulate lead-plant, a federally endangered pine rockland species.

Documentation: U.S. Fish and Wildlife Service. 1990. Endangered and threatened species recovery program. Report to Congress. Superintendent of Documents, Washington, DC.

Natural areas mapping. The Garden is a partner with Metro-Parks in the GIS- and GPS-based mapping effort. The Garden is helping coordinate the development of vegetation maps and will study the biology of the natural areas. It will have computer workstation tied to the one at Metro-Parks.

Documentation: Fisher, Jack B. 1994. Biological monitoring project. Garden News 49(2):36. Fairchild Tropical Garden, Miami, Florida.

University of Miami.

Mangrove biology. Many experimental studies have been done on productivity and decomposition of Biscayne Bay and southeast Dade County mangroves.

Documentation:

Fell, J.W., R.C. Cefalu, I.M. Master, and A.S. Tallman. 1975. Microbial activities in the mangrove (*Rhizophora mangle*) leaf detrital system. Pages 661-679 *in* G.E. Walsh, S.C. Snedaker, and H.J. Teas, editors. Proceedings of the international symposium on biology and management of mangroves. Volume II. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Fell, J.W., and I.M. Master. 1973. Fungi associated with the degradation of mangrove (*Rhizophora mangle* L.) leaves in South Florida. Pages 455-465 *in* L.H. Stevenson and R.R. Colwell, editors. Estuarine microbial ecology. University of South Carolina Press, Columbia, South Carolina.

Hildebrand, E.L. 1977. Mangrove sediments in South Florida: soluble organic carbon and the growth physiology of an epipelic diatom. M.S. Thesis. University of Miami, Coral Gables.

Kimball, M.C., and H.J. Teas. 1975. Nitrogen fixation in mangrove areas of southern Florida. Pages 654-660 *in* G.E. Walsh, S.C. Snedaker, and H.J. Teas, editors. Proceedings of the international symposium on biology and management of mangroves. Volume II. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Miller, P.C. 1972. Bioclimate, leaf temperature, and primary production in red mangrove canopies in South Florida. Ecology 53(1):22-45.

Miller, P.C. 1975. Simulation of water relations and net photosynthesis in mangroves in southern Florida. Pages 615-631 *in* G.E. Walsh, S.C. Snedaker, and H.J. Teas, editors. Proceedings of the international symposium on biology and management of mangroves. Volume II. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Pool, D.J., A.E. Lugo,and S.C. Snedaker. 1975. Litter production in mangrove forests of southern Florida and Puerto Rico. Pages 213-237 *in* G.E. Walsh, S.C. Snedaker, and H.J. Teas, editors. Proceedings of the international symposium on biology and management of mangroves. Volume I. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Rielinger, D.M. 1991. Respiration in black mangrove (*Avicennia germinans* [L.] Stern) pneumatophores under submerged and oiled conditions. M.S. Thesis. University of Miami, Coral Gables.

Teas, H.J. 1974. Mangroves of Biscayne Bay. Report to the Metropolitan Dade County Commission, Miami, Florida.

Teas, H.J. 1976. Productivity of Biscayne Bay mangroves. Pages 103-112 *in* A. Thorhaug, editor. Biscayne Bay: past/present/future. University of Miami, Sea Grant Program, Coral Gables, Florida.

Experimental Hatchery. This hatchery on Virginia Key is a component of the county's Biscayne Bay Restoration and Enhancement Program. It was established in 1983 to investigate the feasibility of marine fisheries enhancement in the bay. The initial target was snook, a state species of special concern. Presently the target species as been red drum, and in recent years thousands of juvenile red drum have been tagged and released in north Biscayne Bay. Local bait shrimp are also being raised.

Documentation:

Biscayne Bay Management Committee. Undated. State of the bay 1991-1992. Annual report of the Biscayne Bay Management Committee and a special guide to Biscayne Bay. Biscayne Bay Management Committee, Miami, Florida.

U.S. Fish and Wildlife Service.

Manatee tracking. Movements of tagged manatees have been followed by ongoing year-round satellite tracking since 1986 and radio tracking since 1978.

Documentation: Dade County Department of Environmental Resources Management. 1994. Dade County manatee protection plan. Partially revised second draft. Dade County Department of Environmental Resources Management, Miami, Florida.

Florida Department of Environmental Protection.

Sea turtle nesting activity status. Since 1979, permits have been issued to individuals, groups, and government agencies to conduct nesting surveys. Following each year's nesting season, permit holders are requested to complete summary forms. These are compiled to assess yearly status of nesting activity throughout the state. The beaches of Subregion 9 with the longest data records are Boca Raton public beach and John U. Lloyd State Recreation Area, surveyed since 1979; and the Broward County beaches, Bill Baggs Cape Florida State Recreation Area, and Miami area beaches, surveyed since 1980.

Documentation:
Conley, W.J., and B.A. Hoffman. 1987. Nesting activity of sea turtles in Florida, 1979-1985. Florida Scientist 50:201-210.
Harris, B.A., W.J. Conley, and J.A. Huff. 1984. The status of Florida's nesting sea turtle populations from 1979 through 1983. Florida Department of Natural Resources, St. Petersburg, Florida.

Florida International University.

Impacts of coastal development on turtle nesting in Broward and Palm Beach counties. A 54-mile section of beach was studied; this represented one of the most heavily developed coastal areas in the world where there is a large population of nesting sea turtles. This was a multifaceted study with projects initiated as early as 1974 by the investigator. Human disturbance and development were quantified by a coastal inventory that was compared to nesting survey data. The inventory showed that beaches in Broward Co. are wider but less vegetated than beaches in Palm Beach Co. Palm Beach Co. had about 2% vacant beachfront. Broward Co. had about 4% vacant beachfront, but its beaches were more highly developed. Natural predation, poaching, boat-related mortality, effects of beach cleaning and nourishment were some of the topics assessed. Nesting was extremely variable, but disturbance variables that contributed to lower nesting densities were heavy night pedestrian traffic on the beaches, proximity of the highway to the beach, presence of fishing piers and associated human activity, proximity of navigational inlets, beach armoring, width and erosion of the beach, and artificial lights. The study concluded that a beach safe for turtle nesting was one with a minimum number of human disturbances and a relatively steep slope. Overall nesting success was highest and incidence of disturbance crawls was lowest at relatively private beaches with little night pedestrian traffic (Hillsboro Beach, private south section of Fort Lauderdale Beach); lowest nesting success was at public, more disturbed beaches (Fort Lauderdale Beach). Nesting generally increased from south to north in the study area. The overall greatest concentration of nests since 1978 was on Hillsboro Beach between the inlet and the Hillsboro Condominium about a mile north; this is an area with private homes vacant during the summer and a Coast Guard Station, with abundant vegetation and virtually no night pedestrian traffic. John U. Lloyd State Park beach, with heavy vegetation, restricted night pedestrian traffic, and devoid of buildings, also had a high concentration of nests. In Palm Beach Co., nesting was greater on private sections of beach than on public sections, such as at Delray Beach.

Loggerheads nested on beaches almost everywhere throughout the area, including sand spits inside Port Everglades and Hillsboro Inlet. Both juvenile and adult green turtles were relatively common in the study area. Observations have shown that the shallow coastal area off both Broward and Palm Beach counties is major developmental habitat for juveniles. In Broward Co., green turtle nesting since 1978 was consistently concentrated in John U. Lloyd State Park and Hillsboro Beach, the least developed areas. Although systematic monitoring was lacking in Palm Beach Co., nesting was concentrated in Boca Raton, the private section of Delray beach, and a section at Phipps Ocean Park and Palm Beach municipal golf course, all areas lacking commercial development. A hawksbill turtle was the likely species that nested in 1988 on Phipps Park beach in Palm Beach Co. Juvenile hawksbills are commonly observed by divers on shallow water reefs in both Palm Beach and Broward counties. A Kemp's ridley turtle has been observed attempting to nest in Palm Beach Co.; the investigator observed a turtle dig a nest on two separate days but did not lay eggs. This observation is the first record of a nesting Kemp's ridley on the Atlantic coast. The investigator saw numerous adult and hatchling leatherbacks in the study area and made numerous observations of females nesting. A headstart program for leatherbacks was initiated in 1982 by the investigator with Ocean World, but it was discontinued because of difficulty in obtaining a sufficient quantity of jellyfish as food.

Although about 750,000 turtles have hatched from relocated nests in the area (the largest conservation effort in Florida), study results suggested the need for an evaluation of the nest relocation strategy. Results indicated an increase in loggerhead and green turtle populations in Southeast Florida, and drastic protection measures may not be needed in the study area, except for the Kemp's ridley. Recommendations included: limit or prohibit night pedestrian traffic on nesting beaches; construct high-profile, vegetated dunes as buffers from highways; prevent operation of mechanical beach cleaning equipment during nesting and hatching season; allow nests to incubate naturally and discontinue nest relocation programs except in emergencies; aggressively enforce limits on beach lights; limit use of lights on piers; conduct education programs to discourage beachfront lighting and dumping of plastic and other debris.

Documentation:

Fletemeyer, J.R. 1990. Kemp's ridley sea turtle nests in Palm Beach. Florida Naturalist 63(1):5.
Fletemeyer, J.R. 1991. The nesting imperative: a study of conflicts between humans and sea turtles on Southeast Florida beaches. Ed.D. dissertation. Florida International University, Miami, Florida.

Florida Game and Fresh Water Fish Commission, Nongame Wildlife Section.

Coastal Wildlife Conservation Plan. Long-range planning to conserve vulnerable coastal wildlife and their habitat involved identifying research tasks needed for conservation and management. Many of these planned projects on coastal strand endemics, shorebirds, neotropical migrants, wading birds, and tidal swamp songbirds apply to biota present in Subregion 9:

Compilation of available information on distribution and ranges of barrier island endemic rodents.
Beach and cotton mouse habitat use patterns on barrier islands.
Effects of land development on local beach mouse populations.
Beach and cotton mouse food habits on barrier islands.
Distribution survey of migrating and wintering falcons.
Subspecific status of migrating peregrine falcons.
Population biology of migrant and wintering peregrine falcons.
Shorebird identification training program.
Development of monitoring techniques for wintering shorebirds and predators.
Development of a monitoring plan for wintering shorebirds.
Distribution survey of wintering shorebirds.
Distribution and abundance of wintering common loons.
Toxicological analysis of dead common loons.

Migration counts at key migratory bird concentration areas.
Completion of tern and black skimmer survey.
Development of a monitoring plan for breeding shorebirds.
Characterization of foraging habitat of breeding least terns and black skimmers.
Relative productivity of roof nesting least terns.
Colonial wading bird survey.
Distribution survey for breeding yellow-crowned night herons.
Develop techniques to locate breeding yellow-crowned night herons.
Survey to determine important foraging and roosting areas for roseate spoonbills.
Food habits and foraging habitat studies of the roseate spoonbill, reddish egret, yellow-crowned night heron, and brown pelican.
Evaluation of impacts of baitfish netting on wading bird food resources.
Effect and extent of cowbird nest predation on mangrove swamp songbirds.
Preparation of guidelines for protection of sea turtle nesting habitat.

Documentation: Millsap, B.A., J.A. Gore, and J.A. Feiertag. 1991. Coastal wildlife conservation plan. Annual performance report, 1 July 1990 - 1 July 1991. Nongame Wildlife Section, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Fairchild Tropical Garden.

Endangered plant propagation. The Garden carries out propagation of plants for the Center for Plant Conservation and maintains a conservation collection of 11 species of South Florida endangered flora. Federally listed plants being propagated that occur in Subregion 9 are the crenulate lead-plant, Small's milkpea, and beach jacquemontia. Horticultural practices are being developed for successful maintenance of wild plants and for enriching the genetic representation of the collection. Also being developed are plans for reintroducing endangered plant and identifying native habitats for experimental reintroductions and *in situ* conservation of species.

Documentation:
Garvue, D. 1994. The Garden's endangered species program. Garden News 49(2):13-14. Fairchild Tropical Garden, Miami, Florida.
U.S. Fish and Wildlife Service. 1990. Endangered and threatened species recovery program. Report to Congress. Superintendent of Documents, Washington, DC.

National Audubon Society.

Breeding bird survey. The NAS conducted a nationwide survey of breeding bird populations to verify presence or absence of nesting by species. Sampling conducted in Florida during 1986-91 included the three counties of Subregion 9. Each county had its own survey coordinator. Verification of Florida data is expected to be completed in 10/94. The Florida atlas will be not be published before the end of 1995 or 1996.

Documentation: Herb Kale, Florida Audubon Society, pers. comm.

University of Florida.

Tree snail distribution and status. The FG&FWFC is providing 1-year funding through the Nongame Wildlife Program for a summary of the historical distribution and current status of the Florida tree snail. (Subreg. 9?)

Documentation: Florida Game and Fresh Water Fish Commission. 1993. Nongame Wildlife Program contracted projects that have been funded by Florida Game and Fresh Water Fish Commission as of September 15, 1993. Table. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

University of Texas at Austin.

Tree snail biology. The FG&FWFC is providing funds through the Nongame Wildlife Program for a 3-year study of genetic variation, systematics, and reproduction of the Florida tree snail. (Subreg. 9?)

Documentation: Florida Game and Fresh Water Fish Commission. 1993. Nongame Wildlife Program contracted projects that have been funded by Florida Game and Fresh Water Fish Commission as of September 15, 1993. Table. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

EDUCATION/SOCIOLOGY/URBAN PLANNING

PALM BEACH COUNTY

Joint Center for Environmental and Urban Problems.

Focus groups on solid waste. A survey was sponsored by the Solid Waste Authority of Palm Beach Co. to gather information on residents' attitudes toward issues such as recycling and composting. Findings showed that residents are willing to recycle more solid waste, but composting is not feasible for the average household.

Documentation: Joint Center for Environmental and Urban Problems. 1993. Biennial Report 1991-1993. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.

BROWARD COUNTY

Joint Center for Environmental and Urban Problems.

Setting the agenda for Broward County's environmental future. This conference was conducted in Fort Lauderdale in 1992 and sponsored by the Broward Dept. of Natural Resources Protection.

Solid waste survey. Conducted in 1993 for the Broward Co. Office of Environmental Services, this survey showed residents' willingness to participate in recycling programs and some support to locate a biosolids facility in the county.

Documentation: Joint Center for Environmental and Urban Problems. 1993. Biennial Report 1991-1993. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.

DADE COUNTY

South Florida Water Management District.

Hispanic community outreach program. In 12/92, SFWMD began a program targeted at the Dade Co. Hispanic community to inform them about South Florida's water resources and what they could do to protect those resources. One component used various communication media, including a celebrity spokesperson, to target the adult community. A second component targets Hispanic youth, ages 5-12, to protect Biscayne Bay in projects such as bay cleanups, pollution prevention, shoreline stabilization, etc. The objective of this RFP is to implement a water resources awareness campaign at the leaders of the Hispanic community. By targeting community leaders, the SFWMD hopes in the long run to educate the community at large on how they can shape Dade Co.'s water resources future, given the county's growth rate and demand on the resources, and how people's individual and collective actions affect these resources. This new program will bring to decisionmakers more substantive educational information about the county's unique environmental challenges.

Documentation: South Florida Water Management District. 1994. Request for proposals (RFP), Hispanic leadership campaign. Issue date March 15, 1994. Procurement and Contract Administration, South Florida Water Management District, West Palm Beach, Florida.

Biscayne Bay Environmental Education Program. Several projects have been carried out through grants from SFWMD and Dade Co., associated with the SWIM program, including development of teaching materials and education programs and production of television public service announcements about problems such as littering. The Miami River Coordinating Committee and Biscayne National Park have also been partners. Baynanza, an annual celebration established in 1982, is a major event to focus public attention on the environmental, historic, cultural, aesthetic, and recreational values of Biscayne Bay. It presents over 30 different events over a period of more than 2 weeks. 5 new projects are proposed: conduct a campaign to make children aware of bay resources and need for protection; implement the Cape Florida interpretive project about habitat restoration; develop a speakers bureau to make business owners aware of the importance of good water quality in the bay; initiate wetland education programs for secondary school students; and prepare a guide to supplement existing middle school environmental education programs.

Documentation:

Alleman, R., D. Black, S. DuToit, S. Formati, C. Gove, and L. Gulick. 1994. An update of the Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. Draft planning document, technical supporting document, and appendices. Lower East Coast Planning Division, South Florida Water Management District, West Palm Beach, Florida.

Biscayne Bay Management Committee. Undated. State of the bay 1991-1992. Annual report of the Biscayne Bay Management Committee and a special guide to Biscayne Bay. Biscayne Bay Management Committee, Miami, Florida.

Joint Center for Environmental and Urban Problems.

A strategy for the redevelopment of South Dade: sustainable and efficient form. At the request of the Florida Energy Office, the Center is creating a structured framework for coordination of planning and design initiatives in the aftermath of Hurricane Andrew. The product will be a conceptual redevelopment master plan that addresses many concerns, including environmental protection.

Documentation: Joint Center for Environmental and Urban Problems. 1993. Biennial Report 1991-1993. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.

REGION

South Florida Water Management District/Joint Center for Environmental and Urban Problems.

Surveys on water use and conservation. The SFWMD sponsored surveys to assess awareness of water shortages and media campaign effectiveness. There is strong public support for water conservation programs and educational efforts to promote water conservation. Information was also gathered on irrigation practices and other outdoor water uses. Palm Beach Co. residents were generally more supportive of paying for a water shortage prevention program; Dade Co. residents were least supportive. Another survey sponsored along with other water management districts showed that residents became less conscious of water use restrictions as rainfall increased and drought effects became less apparent.

Documentation: Joint Center for Environmental and Urban Problems. 1993. Biennial Report 1991-1993. Florida Atlantic University, Boca Raton, and Florida International University, North Miami, Florida.

Florida Game and Fresh Water Fish Commission, Nongame Wildlife Section.

Coastal Wildlife Conservation Plan. Long-range planning to conserve vulnerable coastal wildlife and their habitat involved identifying research tasks needed for conservation and management. One of these is pertinent to conservation education in Subregion 9: Increasing public awareness of sensitivity of shorebird nesting colonies.

Documentation: Millsap, B.A., J.A. Gore, and J.A. Feiertag. 1991. Coastal wildlife conservation plan. Annual performance report, 1 July 1990 - 1 July 1991. Nongame Wildlife Section, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Fairchild Tropical Garden.

Endangered plant exhibit. The Garden carries out propagation of plants for the Center for Plant Conservation and maintains a conservation collection of 11 species of South Florida endangered flora. An exhibit of live rare plants is planned to educate the visiting public. The display will characterize the plants' native habitats and show what is needed to ensure their recovery.

Documentation:
Garvue, D. 1994. The Garden's endangered species program. Garden News 49(2):13-14. Fairchild Tropical Garden, Miami, Florida.

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Alexander, T.R., and A.G. Crook. 1984. Recent vegetational changes in southern Florida. Pages 199-210 *in* P.J. Gleason, editor. Environments of South Florida, present and past II. Miami Geological Society, Coral Gables, Florida.

Alleman, R.W. Undated. Biscayne Bay: a survey of past mangrove mitigation/restoration efforts. Biscayne Bay Restoration and Enhancement Program. Metropolitan Dade County Department of Environmental Resources Management, Miami, Florida.

Alleman, R., D. Black, S. DuToit, S. Formati, C. Gove, and L. Gulick. 1994. An update of the Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay. Draft planning document, technical supporting document, and appendices. Lower East Coast Planning Division, South Florida Water Management District, West Palm Beach, Florida.

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SUBREGION 10:

CALOOSAHATCHEE RIVER BASIN AND SOUTHWEST FLORIDA

INTRODUCTION

This subregion encompasses the Caloosahatchee River watershed; lower Charlotte Harbor estuarine ecosystem, and the coastal system south to Naples Bay; and the Corkscrew regional ecosystem watershed, including the Immokalee agricultural area (Figure 1). The subregion includes Lee County, western Collier and Hendry Counties, southern Glades County, and southeastern Charlotte County.

This chapter summarizes the major ecological and hydrological issues, problems, and threats in this subregion; existing scientific information on these topics; ongoing and proposed research and monitoring projects; identifies scientific information gaps and research that is needed to fill theses gaps. The purpose of this task, and the Science Group, is to provide the necessary scientific information to develop and implement management strategies to restore impacted ecosystems to a naturally functioning, self sustaining state and to prevent further ecosystem degradation. The task was accomplished by meeting with scientists who work in this subregion and by reviewing the scientific literature.

SUBREGION DESCRIPTION

The human population in this subregion is concentrated along the coast, as occurs in most of Florida. The coast is rapidly becoming highly urbanized. The coastal zone in this subregion has the highest growth rate in Florida in the last ten years, and the highest projected growth rate from now to 2010. The Cape Coral - Ft. Myers and Naples metropolitan areas are among the seven fastest growing in the United States. In the 1980s, Collier and Lee County populations grew by 77% and 63%, respectively (SFWMD 1992). Projected population increases for Collier and Lee Counties from 1990 to 2010 are 140% and 90%, respectively (SFWMD 1992).

A somewhat unique aspect of this subregion is large scale "planned" residential development projects, which were conducted from the late 1950s to the early 1970s. Cape Coral, Lehigh Acres, and Golden Gates are the largest of these developments. Cape Coral is the second largest Florida city in area (285 km2). The natural habitats in over 90% of this area were destroyed. Wetlands were filled; terrestrial forests were cleared of vegetation. Over 2000 km of roads and 650 km of freshwater and estuarine residential canals were constructed. During this process most of the land was platted and sold as residential home sites. The projected build out population of Cape Coral is 400,000 people. Population today is 80,000-100,000. Many areas of the city are sparsely populated, however Cape Coral is one of the five fastest growing cites in the country. The environmental impacts of such "mega" developments are discussed below.

Agriculture is a major land use in the interior of this subregion. This subregion probably has the highest rate of land conversion to agriculture, primarily citrus. In the 1980's, irrigated agricultural acreage in Collier and Lee Counties grew by 99% and 35% respectively. Recently, land conversion to citrus has increased substantially. From 1985 to 1990, citrus acreage in Collier, Hendry and Lee Counties increased 134%, 83% and 46%, respectively (SFWMD 1992). This boom in acreage is the result of interregional movement of citrus from central to southwest Florida following several severe freezes in the mid-1980's. The projected increases in citrus acreage for Collier, Hendry, Glades, and Lee Counties from 1990 to 2010 are 150%, 100%, 90%, and 50% (SFWMD 1992). The environmental implications of this conversion are discussed below.

Caloosahatchee River Watershed

The river basin drains an area of about 3700 km^2. The basin extends from Lake Okeechobee to the river mouth in San Carlos Bay. The watershed includes northern Lee and Hendry Counties, southern Glades County, and southeastern Charlotte County.

The Caloosahatchee River was originally a shallow meandering stream about 80 km long with head waters near Lake Hicpochee (Drew and Schomer 1984; Hammett 1990). The river was extended east to Lake Okeechobee by dredging in 1884. The river was first channelized to improve navigation and flood control in the 1930's. Three locks or water control structures were constructed on the river: Moore Haven Lock and Ortona Lock in 1937; and Franklin Lock, near Olga, in the 1960's. The Franklin Lock acts as a salinity barrier. The freshwater portion of the river is 60 km long; the tidal Caloosahatchee extends downstream of Franklin lock for about 45 km. Most of the freshwater entering the Caloosahatchee estuary is through Franklin lock. There are 60 tributaries to the Caloosahatchee River, many are channelized.

The most common land uses in the fresh water portion of the basin are agriculture and rangeland; the tidal basin is primarily urbanized.

Charlotte Harbor Estuarine Ecosystem

The Charlotte Harbor estuarine system includes Charlotte Harbor proper; Pine Island Sound; Matlacha Pass; San Carlos Bay; an extensive barrier island system; and the tidal reaches of the Caloosahatchee, Peace, and Myakka Rivers. The estuary is the second largest in Florida with a surface area of 270 mi^2. The watershed is about 4685 mi^2 (Hammett 1990). There are five national wildlife refuges, four state aquatic preserves, and two state land preserves within the system. Only the lower half of the system is technically part of this project because the upper half is in the Southwest Florida Water Management District (SWFWMD). The management implications of this political division are discussed below.

The system is a shallow, subtropical, coastal plain estuary with an overall mean depth of about 2 m. Water depths in the northern portion are 0.5-1 m greater than the southern. The estuary is separated from the Gulf of Mexico by a series of large barrier islands. Total average discharges to Charlotte Harbor from the Caloosahatchee, Peace, and Myakka Rivers are 2000 cfs, 2000 cfs, and 630 cfs, respectively (Hammett 1990). Direct rainfall contributes about 1000 cfs. The water column is usually partially to thoroughly mixed due to the shallow depths and moderate freshwater inflows (SWFWMD 1993).

Seagrass and benthic macroalgae are abundant in Pine Island Sound and Matlacha Pass. Whereas, deeper Charlotte Harbor proper has less benthic macrophytes; primary productivity is plankton based. The system provides habitat for over 30 threatened or endangered species. The ecosystem supports highly productive fisheries.

Estero Bay Estuary and Watershed

This system located in southwestern Lee County consists of Estero Bay, and associated barrier islands; the Estero Bay basin including the Imperial and Estero Rivers; and the Six Mile Cypress Slough Watershed.

Estero Bay is a shallow, subtropical lagoon (11,300 acres) separated from the gulf by barrier islands. Seagrass beds are common in the bay, however high turbidity restricts seagrasses to shallow depths. (Lee County 1994). Estero Bay differs from Charlotte Harbor in that there are no significant rivers flowing into it, and only weak tidal exchange due to restricted inlets (Godschalk et al 1988). The lands surrounding Estero Bay, including the barrier islands, are highly developed. Estero Bay is a State Aquatic Preserve.

Six Mile Cypress Slough (2000 acres) is characterized by dense cypress interspersed with numerous ponds. The slough has been preserved through the state Save Our Rivers (SOR) Program (SFWMD 1993a).

Corkscrew Regional Ecosystem Watershed (CREW)

The CREW is 58,000 acres of mostly functional wetlands in southeast Lee and north Collier Counties. The watershed contains a variety of habitat types and plant communities, the most common being cypress sloughs (CREW Trust 1992). The National Audubon Society's 11,000 acre Corkscrew Swamp Sanctuary is part of this watershed. The Sanctuary has North America's largest nesting colony of endangered wood storks and largest remaining stand of virgin bald cypress, and the oldest trees in eastern North America (Browder 1984; National Audubon Society 1981). The watershed provides habitat for about 75 endangered or threatened plant and animal species (CREW Trust 1992)

The CREW has significant hydrologic importance to the region. It conveys water to Florida Panther NWR, Fakahatchee Strand State Preserve, Big Cypress National Preserve, and the Estero Bay State Aquatic Preserve Watershed. CREW is on the approved projects acquisition lists of the State SOR and CARL programs. Since 1989 14,000 acres have been acquired (CREW Trust 1992)

Most of the land surrounding the CREW has been converted to agriculture (Immokalee agricultural area). Winter vegetables are the primary crop, but citrus is increasing.

Hydric Pine Flatwoods

The hydric pine flatwood ecosystem is characterized by a slash pine dominated upperstory and wetland plant understory (Beaver and Dryden 1993). The longer hydroperiod and wetland understory differentiate this ecosystem from xeric and mesic pine flatwoods. Only recently have scientists and government regulatory agencies recognized hydric pine flatwoods as a separate community or ecosystem type.

Hydric pine flatwoods covered at least 200,000 acres in southwest Florida in 1989 (Beaver and Dryden 1993). This ecosystem type also occurs in Subregion 3 (Martin and Palm Beach Counties).

The hydric pine flatwoods of southwest Florida have regionally significant ecological and hydrological value. Plant species diversity is high: over 900 species, including 85 protected species (Beaver and Dryden 1993). At least 21 federal and state listed animal species utilize this ecosystem. Hydric pinelands are thought to be important to groundwater recharge (Beaver and Dryden 1993).

ENVIRONMENTAL PROBLEMS AND ISSUES

Alteration of Natural Freshwater Inflow to Estuaries

As elsewhere in South Florida, the natural pattern (quantity and timing) of freshwater inflow to estuarine ecosystems in this subregion has been altered by anthropogenic activities. These activities include channelization, dredging, and filling for flood control, navigation, wetland drainage, and urban and agricultural land development.

<u>Caloosahatchee Estuary</u>

The natural pattern (quantity and timing) of freshwater flow into the Caloosahatchee estuary has been disrupted due to its unnatural connection to Lake Okeechobee, water control structures on the river, the network of channelized tributaries and drainage canals in the basin, and urban and agricultural water demands (Drew and Schomer 1984; Hammett 1990; SFWMD 1993b). Periodic regulatory releases from Lake Okeechobee are made to the estuary via the river. During such releases the volume of freshwater entering the estuary can be $>10{,}000$ cfs (SFWMD 1993b). These releases usually occur during the latter part of the dry season when freshwater inflow would naturally be lowest. Because of these discharges the freshwater flow into the estuary exceeds the historical volume, especially in the dry season. Conversely, when regulatory discharges are not occurring, unnaturally low freshwater inflow can

occur during the dry season due to high water demand for agricultural and urban uses. (SFWMD 1993b). The network of channelized tributaries and drainage canals exacerbates the excessive discharge problem.

Several studies indicate that this altered flow pattern impacts the Caloosahatchee Estuary. Discharges >6000 cfs from Franklin Lock cause the entire estuary to become oligohaline and can decrease salinity in the outer embayments, San Carlos Bay and Matlacha Pass (Chamberlin 1992; Bierman 1993). Submerged vegetation in estuary has decreased significantly since the installation of Franklin Lock (McNulty 1972; Harris et al 1983; SFWMD 1993b). Other studies suggest impacts on water quality, benthic fauna, and fisheries (summarized in SFWMD 1993b).

Spreader Waterways and Cape Coral

The concept of "spreader waterway" was developed as a mitigation technique to reestablish sheet flow of water in wetlands that are anthropogenically altered. Spreader systems seem to most common in southwest Florida. Cape Coral, with a 40km long spreader waterway, is the best example.

Construction of the 650 km Cape Coral residential canal system altered the natural freshwater sheet flow pattern into Matlacha Pass (Charlotte Harbor). A spreader waterway was constructed to reestablish sheet flow. The spreader system is not functioning properly (Morrison et al 1990). There are numerous breaches resulting in channelized freshwater flow into Matlacha. This channelized inflow has eliminated or degraded seagrass and mangrove habitat and reduced seagrass productivity (Morrison et al 1990).
The Cape Coral and other dysfunctional spreader systems question the validity of this mitigation method.

Faka Union Bay and Golden Gates

Construction of the Faka Union and Golden Gates Estates canal systems altered the natural freshwater sheet flow into Faka Union Bay and adjacent estuarine areas (Browder et al 1989; SFWMD 1994). The canal systems increase the rate of surface water runoff resulting in substantial point loads of freshwater into the estuaries. This alteration has had the following effects on the estuarine ecosystem: altered natural salinity regime and freshwater shocks; decreased the nursery value for fish and shellfish by reducing area with salinity ranges favorable for planktonic and juvenile forms; reduced abundances of subadult and adult fish; increased nutrient loading; and long term negative effects on habitat quantity and quality, including likely decline in seagrass coverage (Browder et al 1989; SFWMD 1994).

Charlotte Harbor Estuarine Ecosystem

The environmental quality of Charlotte Harbor is generally considered to be better than most Florida estuaries. However, significant habitat loss and water quality degradation has occurred over the last 30 to 50 years.

Seagrass and salt marsh acreage decreased 29% and 51% from 1945 to 1982 (Harris et al 1983). However, mangrove forest acreage appears to have increased 10% during this period. Additional seagrass and saline marsh loss and alteration occurred from 1982 to 1990 (Morrison et al 1990; B. Reppenning, FDEP, pers. comm.; L. Riley, Lee County, pers. comm.). Submerged vegetation in the lower Caloosahatchee estuary has decreased significantly since the installation of Franklin Lock (SFWMD 1993b). These losses are attributed to anthropogenic activities, especially large land development projects, causeway construction, and alteration of freshwater inflow patterns.

Nutrient loads, especially nitrogen, entering the estuary have been increasing for the past 15-20 years. Nitrogen and phosphorus inputs via the Caloosahatchee River and nitrogen input from the Peace River have risen (McPherson and Miller 1990; Hammett 1990). Increased urban, especially wastewater treatment plants, and agricultural development account for the greater nutrient loading. Furthermore, urban growth alone is predicted to enlarge nitrogen loading by 20% by 2020 (Hammett 1990). Primary production in the estuary appears to be nitrogen limited

(Montgomery et al 1990; McPherson and Miller 1990). The projected increased nitrogen loads favor undesirable growth of phytoplankton and benthic algae (McPherson and Miller 1990).

Turbidity and suspended particulates have also increased throughout the estuary (McPherson and Miller 1987; Hammett 1990). Suspended, non-chlorophyll particulate matter is the primary cause of water column irradiance attenuation in the estuary (McPherson and Miller 1987). Thus, light reaching benthic vegetation has likely decreased in recent years. Irradiance may limit benthic vegetation growth in parts of the estuary, especially deeper water (McPherson and Miller 1987). The predicted greater phytoplankton density with increased nitrogen loading would further decrease irradiance and inhibit seagrass growth.

Mosquito pesticide application (aerial spraying) is conducted extensively in the Charlotte Harbor system. Lee County has one of the largest mosquito control programs in the country. There is concern and debate about potential ecological impacts of mosquito pesticide application in the mangrove ecosystem. Temephos (abate), a larvicide, is used in the estuary, including national wildlife refuges. Temephos can be toxic to aquatic invertebrates, especially crustaceans (Clark 1993). However, Pierce et al (1989) did not observe acute toxicity to five species of crustaceans and fish in field species. Temephos can persist for several days (Clark 1993). FDEP does not permit temephos application on Charlotte Harbor State Aquatic Preserves. USFWS has recently ordered Lee County Mosquito Control to cease spraying temephos on NWRs. Fenthion (baytex), an adulticide, is also used in Lee County around Charlotte Harbor. It is very toxic to marine invertebrates (Clark 1993). There is concern about drift of fenthion into mangroves. Faunal mortalities in State Aquatic Preserves may have been caused by fenthion drift (B. Reppenning, FDEP, pers. comm.). The aquatic half-life of fenthion is 4 to 7 days (Clark 1993). No chronic or sublethal effects field studies have been conducted (Clark 1993).

Low dissolved oxygen (DO) levels, high chlorophyll a concentrations, and high sediment metal concentrations have been reported in the tidal Caloosahatchee (DeGrove and Nearhoof 1987; SFWMD 1993b). However, water quality data for the tidal Caloosahatchee are insufficient for temporal analysis (DeGrove and Nearhoof 1987).

The numerous residential canal systems that feed into the estuary likely contribute to estuarine water quality degradation. For example, the 250 km Cape Coral estuarine canal network has significantly poorer environmental quality (lower DO and benthic invertebrates; higher nutrients, sediment metals, and turbidity) than the Caloosahatchee estuary (Morrison 1989).

Freshwater Caloosahatchee River

The freshwater Caloosahatchee is a severely stressed ecosystem, with substantial water quality problems. State water quality standards have been frequently exceeded (DeGrove and Nearhoof 1987). Water quality problems include low DO; high nutrients (total nitrogen usually >1.5 mg/L, total phosphorus usually >0.1 mg/L); high chlorophyll a and undesirable algal blooms; and high water column pesticide and metal concentrations (DeGrove and Nearhoof 1987). Lake Okeechobee discharge and basin runoff contribute pollutants to the river; however, there is conflicting information on which source most affects river water quality (Camp, Dresser, and McKee 1991a).

Estero Bay Estuary and Watershed

Water quality in Estero Bay is generally considered to be fair to good; however, degradation has occurred in recent years (Godschalk and Associates 1988; Lee County 1994). Nutrient and turbidity levels have increased. Estero Bay sediments are enriched in cadmium, lead, and zinc. The freshwater inflow pattern has been altered. Water quality problems are attributed to increased urbanization of the watershed, and also for turbidity increased boat traffic. Urbanization in the watershed is projected to increase by over 130% (based on number of dwelling units) from 1986 to 2010 (Godschalk and Associates 1988). Environmental quality in Estero Bay is particularly vulnerable to future degradation due to poor flushing, the bay's low volume, and increasing urbanization of the watershed (Godschalk and Associates 1988).

The natural hydroperiod and water flow pattern in Six Mile Cypress Slough has been altered (Lee County and SFWMD 1988; SFWMD 1993a). Exotic plant invasion is a problem (SFWMD 1993a; Lee County 1994). The southern one third of the slough is heavily infested with Melaleuca.

Citrus Development and Agriculture Issues

As discussed above, there has been and will continue to be considerable conversion of uplands and pasture lands to citrus. Much of the current and proposed citrus development occurs in an area with diverse fauna and flora including 31 federal and state protected species (Mazzotti et al 1993), and adjacent to valuable wetlands. There is concern about the potential effects of citrus development on plants, wildlife, and their habitats and surface and groundwater quality and quantity. However, there are few studies that evaluate possible impacts.

Agriculture dominates water use in the interior of this subregion (SFWMD 1992). Citrus uses more water per acre than any type of agriculture, except plant nurseries (Hammett 1990). More water use permits are issued for citrus than any other agricultural type (Mazzotti et al 1993). From 1990 to 2010, water demand by citrus in Collier, Glades, Hendry, and Lee Counties is projected to increase 130%, 80%, 70%, and 35%, respectively (SFWMD 1992). Citrus farming causes lower water tables, which impacts hydrology and the structure and function of wetlands (SFWMD 1992).

Citrus has lower biological habitat value than pasture, upland, and wetlands -- the habitats most likely to be converted to citrus (Mazzotti et al 1993). Most species occurring in citrus groves inhabit agricultural reservoirs, temporary ponds or seasonal wetlands in groves (Mazzotti et al 1993). In addition to habitat loss, another consequence of citrus conversion is fragmentation of remaining high quality habitat (Mazzotti et al 1993). Mazzotti et al (1993) develop and evaluate alternatives for integrating biological conservation and citrus development in southwest Florida.

Corkscrew Regional Ecosystem Watershed (CREW)

All lands around the CREW are undergoing intense development pressure from agriculture and other land uses (CREW Trust 1992). Much of the surrounding lands have been converted to agriculture, mainly vegetables but more recently citrus. The ecological and hydrological effects on the CREW are not known.

Two municipal wellfields have cones of influence that extend into the CREW (CREW Trust 1992). There is concern that these wellfields are lowering groundwater and surface water in CREW wetlands, affecting wetland hydrology and ecology. A SFWMD contract study is evaluating the potential impacts of wellfield withdrawal (CREW Trust 1992).

Pine flatwoods in parts of the CREW were clear cut in 1989-90 for conversion to citrus. However, SFWMD has acquired the land; natural reforestation is taking place (CREW Trust 1992). Invasive exotic plants, especially Melaleuca, pose a serious ecological threat if not controlled. Oil exploration occurs in the CREW. Residential development adjacent to CREW is increasing.

A SFWMD contract project assessing CREW hydrologic, hydrogeologic, and biological resources was recently completed (Gee and Jenson 1993). This study provides strategies for protecting CREW ecological and hydrological resources.

Hydric Pine Flatwoods

Large acreages of hydric pine flatwoods have been lost to logging, development, and agricultural activities (Beaver and Dryden 1993). Habitat destruction from residential and commercial development and citrus conversion continues. Melaleuca and other invasive exotic plants are a serious ecological problem. Anthropogenic activities alter the natural surface and ground water hydrology. Drainage of

hydric pinelands greatly increases susceptibility to exotic plant invasion (Wade et al. 1980).

Naples Bay Ecosystem

The Naples Bay estuarine ecosystem includes Naples Bay, Gordon River, Rock Creek, Haldemen Creek, and Gordon Pass. Water quality in this system has degraded (Collier County 1993a). Water quality problems include high nutrient levels (especially ammonia), high chlorophyll a, low DO, and high fecal coliform bacteria. State water quality standards have been frequently violated, especially bacteria. Water quality problems are partially attributed to increased urbanization of the watershed.

CURRENT AND PROPOSED RESEARCH

Alteration of Freshwater Inflow to Estuaries

Caloosahatchee Estuary

SFWMD recently developed a research plan that addresses the Caloosahatchee estuary freshwater inflow problem (SFWMD 1993b). The objectives of the plan are:

1. Determine the optimal freshwater inflow range (quantity and timing) that provides the salinity gradient necessary for healthy biological communities.

2. Develop "real-time" field monitoring and management capabilities.

3. Establish estuarine water quality and nutrient loading limits.

4. Protect endangered species.

Ongoing or proposed research activities include:

- Evaluate alternative Lake Okeechobee release schedules (includes developing ecological performance measures based on indicator species).

- Salinity modeling and monitoring.

- Biota assessments.

- Water quality and basin nutrient loading assessments.

If implemented as proposed this program should provide the necessary scientific information to facilitate the restoration of an appropriate freshwater flow pattern into the tidal Caloosahatchee. However, the indicator species approach should be independently evaluated. Also, SFWMD should immediately establish a comprehensive water quality monitoring program in the Caloosahatchee estuary, as exists in the St. Lucie estuary (Germain 1994).

Charlotte Harbor System

SWFWMD: Identification of optimal freshwater flows. For SWFWMD portion only. (See SWFWMD 1993).

USGS: Salinity distribution and model related to freshwater inflow.

Faka Union Bay and Golden Gates

SFWMD:

- Developing a hydrologic restoration plan for southern Golden Gates Estates to meet the following goals: wetland hydroperiod and surface water sheetflow restoration; restore more natural freshwater inflow pattern to estuaries; improve groundwater recharge; enhance surface water deliveries to Fakahatchee Strand; and, reduce overdrainage of Fakahatchee Strand and Florida Panther NWR lands (SFWMD 1994).

Collier County:

- Surface and groundwater quality monitoring in Golden Gates Estates and Faka Union Canal system (Collier County 1993b)

Charlotte Harbor Estuarine Ecosystem

SWFWMD (for SWFWMD portion only; see SWFWMD 1993 for description):

- Water quality monitoring program
- Development of resource-based water quality targets and pollutant load reduction goals.
- Habitat mapping and assessment.
- Toxics assessment
- Diagnostic watershed assessment: quantification of point and nonpoint source pollution.

SFWMD (for Caloosahatchee Estuary only; see SFWMD 1993 for description):

- Water quality and basin nutrient loading assessments.
- Salinity modeling and monitoring.
- Biota assessments.

USGS: Charlotte Harbor Environmental Assessment Program (see SWFWMD 1993 for description).

Only work left is completion of following project reports:

- Tidal flow, circulation, and flushing characteristics.
- Salinity distribution and model related to freshwater inflow.
- Physical, chemical, and biological characteristics under present and future environmental conditions.

FDEP, FMRI (M. Mitchell, pers. comm.):

- Fisheries independent monitoring program: provide long-term data base on juvenile fish abundance and fisheries abundance trends.

- o Seagrass and other habitats mapping: currently conducting habitat change analysis for period 1982-1992.

- o Assessment of seagrass damage by boat propeller scarring.

- o Functional assessment of seagrass beds: includes assessment of fish and invertebrate assemblages.

- o Long-term seagrass monitoring: detailed in situ monitoring of seagrass distribution, composition, abundance, and productivity.

USFWS:

- o Migratory bird inventories (Refuges, ongoing)

- o Potential impacts of mosquito pesticide spraying on living resources and FWS lands (Ecological Services, proposed).

Mote Marine Laboratory:

- o Sublethal effects of mosquito pesticides on non-target organisms.

FGFWFC:

- o Bird rookery inventories

City of Cape Coral (C. Jarvis, pers. comm.):

- o Water quality monitoring of Cape Coral canal system.

Lee County (L. Riley, pers. comm.):

- o County is developing a surface water management plan that will include water quality monitoring.

- o Seagrass and wetland habitat mapping and trend analysis (GIS based).

Freshwater Caloosahatchee River

SFWMD:

- o Water quality monitoring at locks (see Germain 1994).

- o SFWMD has contracted with Camp, Dresser, and McKee to develop a basin assessment for the river basin (upstream of Franklin Lock. Phase One, which includes literature review (Camp, Dresser, and McKee 1991a); documentation of point and nonpoint pollution sources (CDM 1991b); hydrologic model selection (CDM 1991c); monitoring program design (CDM 1992a); and QA/QC plan (CDM 1992b), has been completed. The pollutant source documentation (CDM 1991c) is inadequate because CDM conducted only a one day, qualitative, field survey. Phase Two will entail water quality and quantity monitoring and data analysis. Phase Three encompasses entering collected data in the SFWMD GIS data base; computer modeling; and developing management recommendations.

Lee County (J. Cassani, pers. comm.):

- Aquatic Plant Control Division is conducting water quality, aquatic macrophyte, and benthic invertebrate monitoring or surveys.

USGS:

- Water quality and other studies will be conducted as part of the National Water Quality Assessment Program (McPherson 1994).

Estero Bay Estuary and Watershed

Lee County:

- Water quality monitoring in southern Estero Bay.
- Hydrologic study of Six Mile Cypress basin as part of Lee County Surface Water Master Plan.
- Water quality monitoring in Six Mile Cypress Slough.
- Effectiveness of various herbicide treatments to control exotic plants in Six Mile Cypress Slough.

Citrus Development and Other Agricultural Issues

SFWMD:

- Contracted comprehensive environmental assessment of preserved and created wetlands within a citrus development in Caloosahatchee basin (Gator Slough). Data collection complete; report in preparation.

USFWS:

- Proposal to investigate environmental contaminant (nutrient, pesticide, metals) inputs and effects to Florida NWR from agricultural runoff (D. Morrison and K. Edwards, unpublished proposal).

University of Florida, IFAS:

- Proposal to assess water quality of agriculture runoff flowing into CREW; to determine the effectiveness of wet detention areas to improve water quality of agriculture runoff; and to modify and verify a computer model for assessing the hydrologic and water quality effects of citrus grove design and management practices (J. Capece, unpublished proposal).

Corkscrew Regional Ecosystem Watershed (CREW)

SFWMD:

- Contract study to ascertain CREW hydrologic, hydrogeologic, and ecological resources. Project includes evaluating impacts of adjacent wellfields; developing monitoring network and baseline data; inventory and map (GIS) plant communities and habitat types; integrating habitat types and their water needs; and developing strategies for protecting CREW hydrological and ecological resources (CREW Trust 1992). Recently completed (Gee and Jenson 1993).

University of Florida, IFAS:

- Proposal to assess water quality of agriculture runoff flowing into CREW; to determine the effectiveness of wet detention areas to improve water quality of agriculture runoff; and to modify and verify a computer model for assessing the hydrologic and water quality effects of citrus grove design and management practices (J. Capece, unpublished proposal).

FGFWFC:

- Will conduct wildlife surveys, including population censuses of game and non-game species (CREW Trust 1992).

Lee County:

- Developing surface water management program which will include water quality monitoring.

Naples Bay Ecosystem

Collier County:

- Limited water quality monitoring

RESEARCH NEEDS

Alteration of Freshwater Inflow to Estuaries

- Freshwater flow pattern into the tidal Caloosahatchee: The indicator species approach proposed by SFWMD should be independently evaluated. Also, SFWMD should immediately establish a comprehensive water quality monitoring program in the Caloosahatchee estuary.

- Research is needed on spreader waterways to determine best design to perform intended ecological and hydrological functions.

Charlotte Harbor Estuarine Ecosystem

- A comprehensive, integrated SWIM plan must be developed for the entire system. Major research and monitoring projects should also be system-wide.
  Two water management districts share jurisdiction for the Charlotte Harbor system (like Indian River Lagoon). However, unlike Indian River, there is no joint system-wide SWIM plan. SWFWMD has a SWIM plan for its portion, but SFWMD does not for its portion. Likewise, most SWFWMD research and monitoring projects cover only SWFWMD jurisdiction.

- GIS based habitat and land use trend analyses for the entire system should be conducted every 3 to 4 years.

- Water quality monitoring program for the SFWMD portion, including tidal Caloosahatchee, to compliment SWFWMD part.

- System-wide nutrient and other pollutant loading study (including septic tanks).

- System-wide hydrologic and circulation model (current USGS study may meet this need).

- o Diagnostic watershed assessment for SFWMD part to compliment that being done in SWFWMD portion.
- o Nutrient limitation and dosing experiments on seagrass - seagrass epiphyte - fleshy macroalgae - phytoplankton complex. Ideally in several areas of estuary.
- o Irradiance limitation and sedimentation experiments on seagrass. Closely coupled with nutrient limitation study.
- o Develop predictive model of benthic vegetation change related to pollutant loading.
- o Freshwater inflow studies: see that section.
- o Field and laboratory studies of chronic and sublethal effects of mosquito pesticides to non-targets species (various life stages), especially repeated applications and extended exposure.
- o Mosquito adulticide drift studies and ecological effects.
- o Continued research into alternative (non-pesticide) mosquito control methods.

Freshwater Caloosahatchee River

- o Basin-wide nutrient and other pollutant loading study.
- o Basin-wide GIS-based habitat trend analysis every 3-4 years.
- o Assessment of biological resources in river.

Estero Bay Estuary and Watershed

There is little information on the ecology and hydrology of Estero Bay. The following studies are recommended:

- o Assessment of biological resources in bay, especially seagrass beds.
- o Basin-wide nutrient and other pollutant loading study.
- o System-wide water quality monitoring.
- o Bay circulation and flushing model.
- o Watershed hydrologic study, particularly addressing altered freshwater flow into Estero Bay.
- o Nutrient limitation and dosing experiments on seagrass - seagrass epiphyte - fleshy macroalgae - phytoplankton complex.
- o Irradiance limitation and sedimentation experiments on seagrass. Closely coupled with nutrient limitation study.
- o Develop predictive model of benthic vegetation change related to pollutant loading.

Citrus Development and Other Agricultural Issues

- Develop techniques to improve irrigation efficiency and water conservation (surface and groundwater).
  Agriculture so dominates water use in the interior that even small improvements in efficiency would result in considerable water conservation (SFWMD 1992).

- Investigate potential ecological effects of agriculture on surface and groundwater quality; ecological effects of surface water runoff from agricultural lands.

- Investigate potential ecological and hydrological effects of lowered water table, particularly in wetlands, from agricultural activities.

- More information is needed on the potential effects of environmental contaminants (pesticides, nutrients, metals) on wildlife in citrus groves.

- Develop a system for evaluating ecological and hydrological functions that can be used to better assess predevelopment environmental conditions and the success of mitigation.

Corkscrew Regional Ecosystem Watershed

- System-wide habitat trend analysis every 3 or 4 years (GIS based).

- System-wide surface and groundwater quality assessment (GIS based) [Gee and Jenson 1993].

- Investigate ecological and hydrological effects of agriculture adjacent to CREW, especially potential nutrient and other contaminant loading from agriculture runoff.
- Examine possible hydrological and ecological impacts of oil exploration.

- Investigate ecological and hydrological effects of residential development adjacent to CREW.

- Investigate ecological and hydrological effects of municipal wellfields adjacent to CREW.

- Flintpen Strand subbasin hydrologic and hydraulic study to assess the impact of new and proposed controlling structures in Kehl canal system (Gee and Jenson 1993).

Hydric Pine Flatwoods

The following recommended research needs are from Beaver and Dryden (1993).

- Recognition of hydric pine flatwoods as a separate biological community type. Landscape scale inventory and monitoring, including historical distribution and aerial coverage, temporal changes.

- Floral and faunal inventory and monitoring, including protected species. Examine wildlife habitat value of hydric pine flatwoods.

- Ecological and hydrological effects of invasive exotics.

- Hydrologic studies including surface water hydrologic conditions need to maintain system and groundwater recharge potential.

- Influence of fire regimes in maintaining natural plant species composition and diversity.

Naples Bay Ecosystem

- o Assessment of biological resources in bay.
- o Basin-wide nutrient and other pollutant loading study.
- o System-wide water quality monitoring.

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