FINAL REPORT

RESEARCH WORK ORDER NO. 139

RESEARCH OBJECTIVES TO SUPPORT THE SOUTH FLORIDA ECOSYSTEM RESTORATION INITIATIVE–WATER CONSERVATION AREAS, LAKE OKEECHOBEE, AND THE EAST/WEST WATERWAYS

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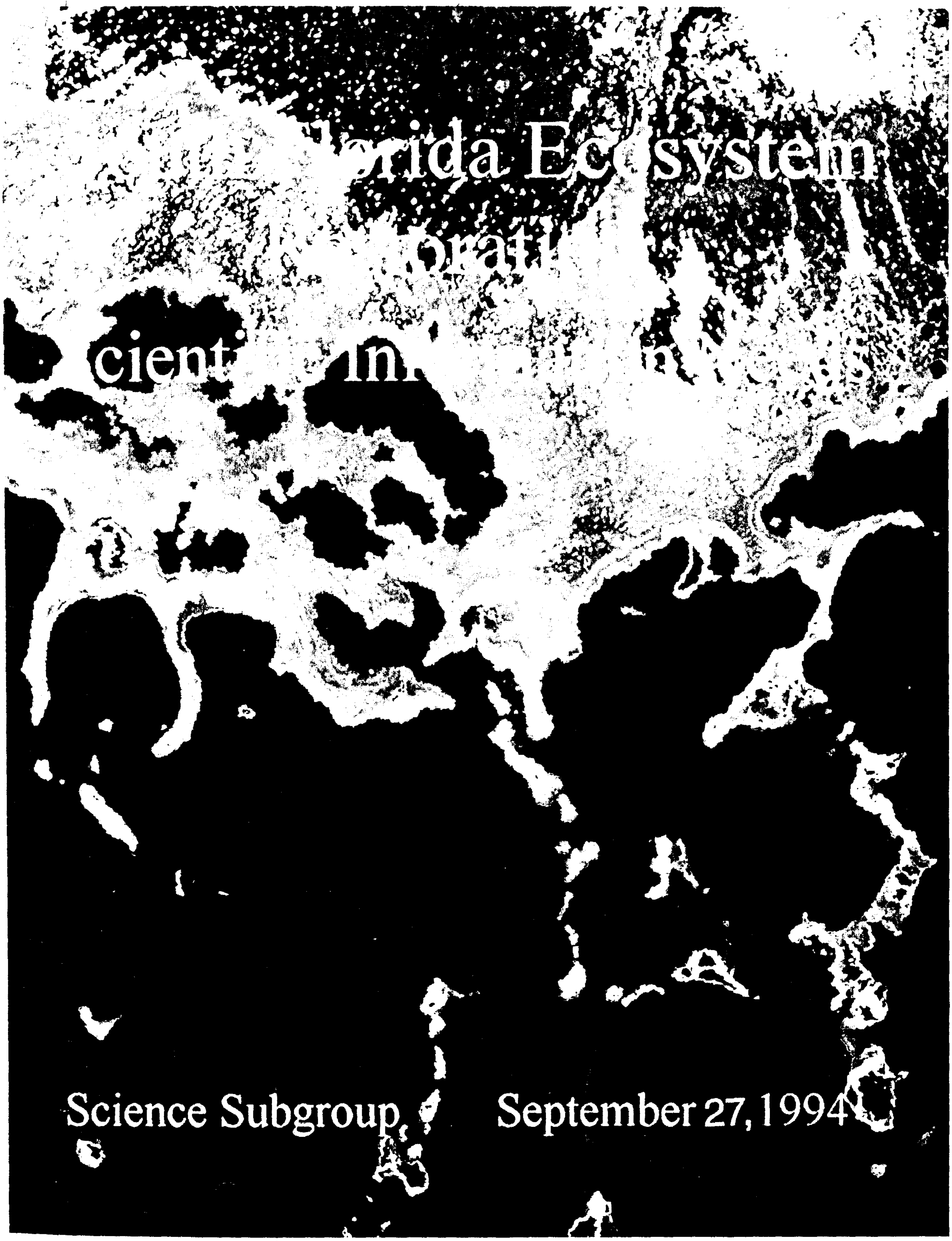
Science Subgroup, September 27, 1994

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.

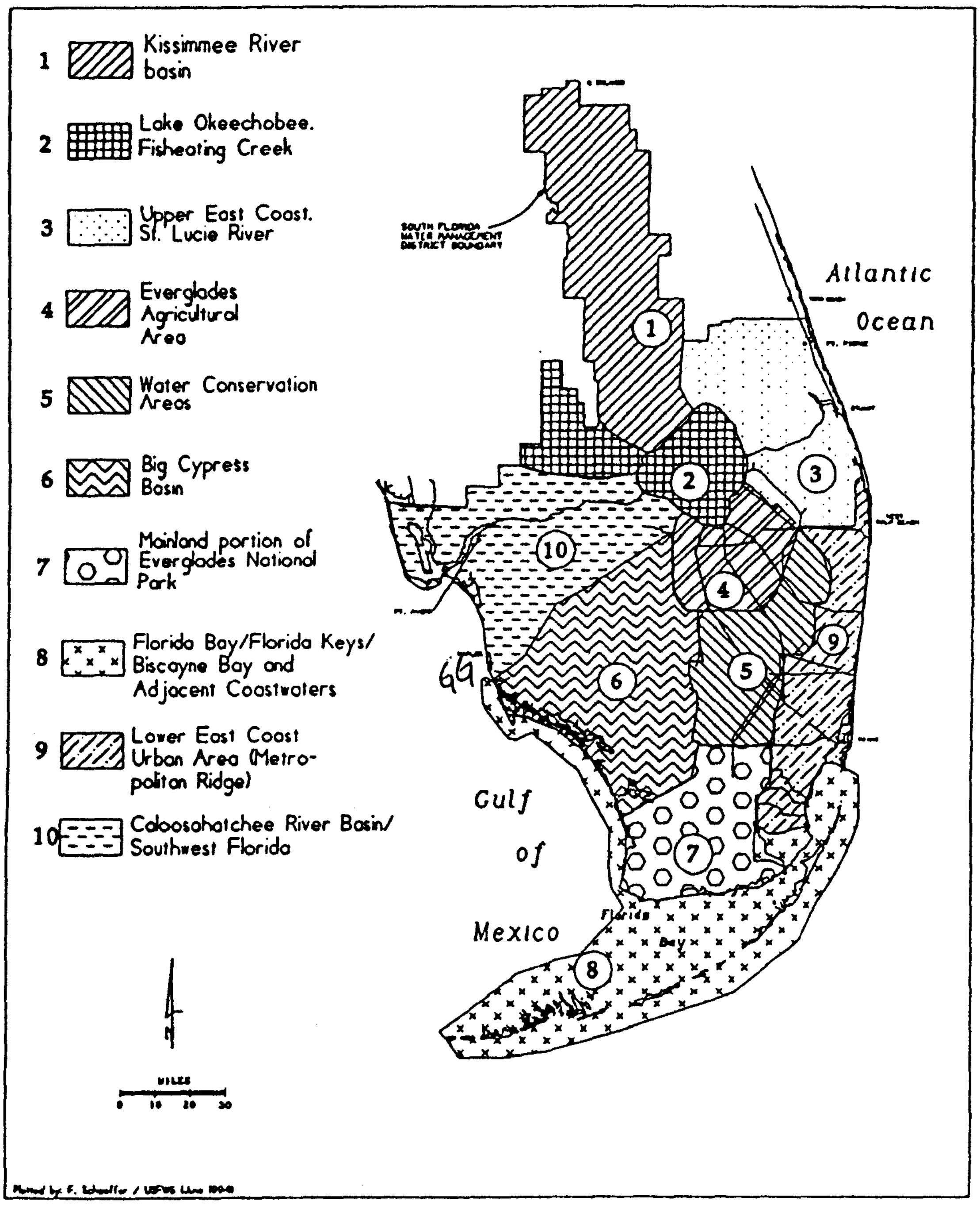

Figure 1. **SUB-REGIONS FOR REVIEW OF ACTIONS TO RESTORE ECOSYSTEMS IN SOUTH FLORIDA**

- 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 require-ments	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.

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 l be developed to investigate vegetative community types and their spatial distribution and dynamics that can ɔected to develop in the expanded littoral zone. These models should be designed to incorporate management ıs such as lake stage regulation and prescribe fire.

Once hydrology and vegetation models are developed, additional models of the responses various animal ıunities to changes in configuration, extent, composition, and hydrology of the littoral zone should be oped. Again, these models can be used to investigate the impacts of various management actions on animal nunities.

Once the expanded littoral zone is established, long-term monitoring of vegetative and animals communities ld be conducted. This will provide basic information on relationships between forcing functions (hydrology, drought, etc,) and response endpoints (vegetation, wading birds etc.). Statistical relationships between forcing :ions and key ecosystem attributes can be refined. Long-term monitoring will also provide critical information termine if the ecological restoration goals are being met. These monitoring programs should be integrated with ɜ developed for other regions in the South Florida ecosystem. The Science-Sub groups recommends monitoring tation, fish (game and non-game), wading birds, and snail kites as part of an integrated approach to evaluate ;uccess of restoring part of the littoral zone. These monitoring efforts will supplement the water quality and ι 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.

ɜarch 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 hern islands should be integrated into existing hydrologic models. The output from these models can be used etermine the potential impacts to these areas under different regulation schedules so as not to negatively impact e 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.

;earch question: What are the impacts of exotic plants on the Lake Okeechobee system and how can these ɔacts be mitigated.

Approach: The first step is to determine the distribution of exotic plant species. Next, the relationships ween lake stage, altered fire regime, water quality and the distribution/abundance of exotics should be determined gradient analysis. This will provide information useful in understanding the mechanisms associated with persal, 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

he Lake Okeechobee Research Plan (LORP) defines a series of management ɔjectives and research activities for Lake Okeechobee, identifies information ɘquirements and provides an initial framework for decision analysis.

For the next year the majority of effort by the Kissimmee and Okeechobee ystems Research Division (KOSRD) will be to complete the analysis and publication f research and monitoring efforts that have been undertaken to date. Future esearch directions will be based on analysis, integration, publication, and ecommendations from past studies. No new research initiatives, in-house or ontractual, will be initiated during the next year without the existence of a ompelling need.

The research plan was developed with input from many individuals involved vith research and monitoring of Lake Okeechobee, including the Lake Okeechobee ſask 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.

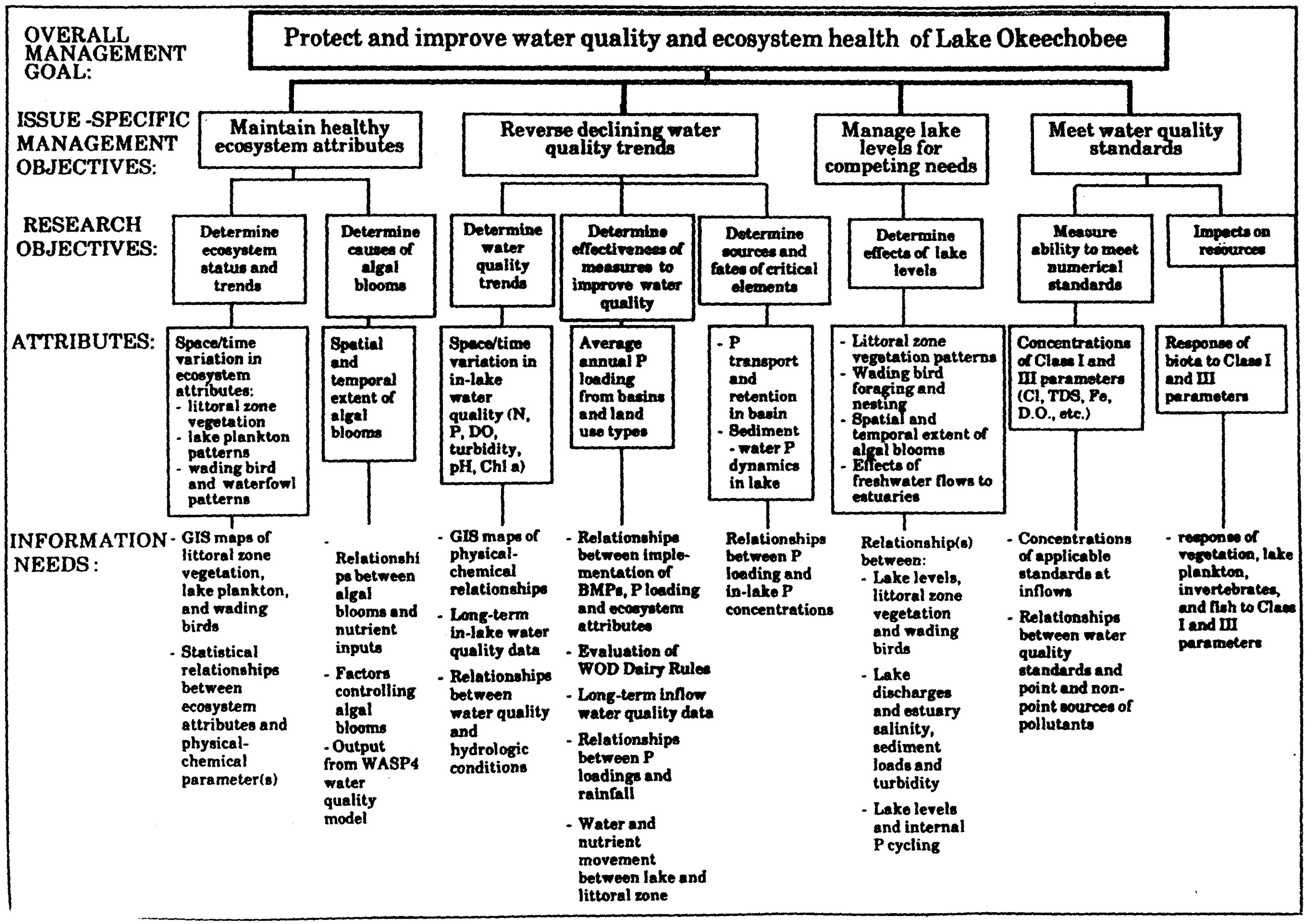
The research plan consists of a chronology of Lake Okeechobee research milestones and huistorical funding levels. Figure 3 illustrates the overall research objectives hierarchy for Lake Okeechobee, including seven research objectives, with their accompanying attributes and information needs . Each of 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

	FY 92-93 O N D J F M A M J J A S / FY 93-94 O N D J F M
•Phytoplankton Nutrient limitation	- - --> x
•Decoupling of suspended solids and chlorophyll	- - - - - - - -> x
•Spatial heterogeneity in plankton	- - - - - - - -> x
•Dye study - littoral/pelagic zone	- - - - - - - - - - - - - - - - -> x
•Class I/III Contract	- - - - - - - - - - - - - - - - ->x
•USGS Monitoring Contract	- - - - - - - - - - - - - - - - ->x
•Y-trips Lake Okeechobee	- - - - - - - - - - - - - - - - - ->x
•Water Quality Conditions Report	- - ->x
•Nutrient loading trends and targets	- - - - - - - - - - - - - - ->x
•Uncertainty analysis, Nutrient budgets	- - - - - - - - >x
•Literature review, water quality research	- - - - - - - - - - - - - - - ->x
•Lake and tributary water quality trends	- - - - - - - - - - - - - - - - - ->x
•Phosphorus Dynamics study	- - - ->x
•Nitrogen impact assessment Contract	->x
•Take Toho water quality improvemenmts	- - - - - ->x
•Science and management case study	- - - - ->x
•Initial results of WASP4	- - - - - ->x
•20-year hindcasting WASP4	- - - - - - - - - - ->x
•Spatial enhancement of WASP4	- - - - - - - - - ->x
•Watershed P transport model	- - - - - - - - ->x
•Update GIS Coverages	- - - - - - - - -> x
•Organic P Contract	- - - - - - - - - ->x
•P stability contract	- - - - - - - - - ->x
•P assimilation in wetlands	- - - - - ->x
•P synthesis contract	- - - - - - - - - - - - - - - ->x
•LOADSS verification	- - - - ->x
•Contaminated ditch contract	- - - - - - - - - ->x

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

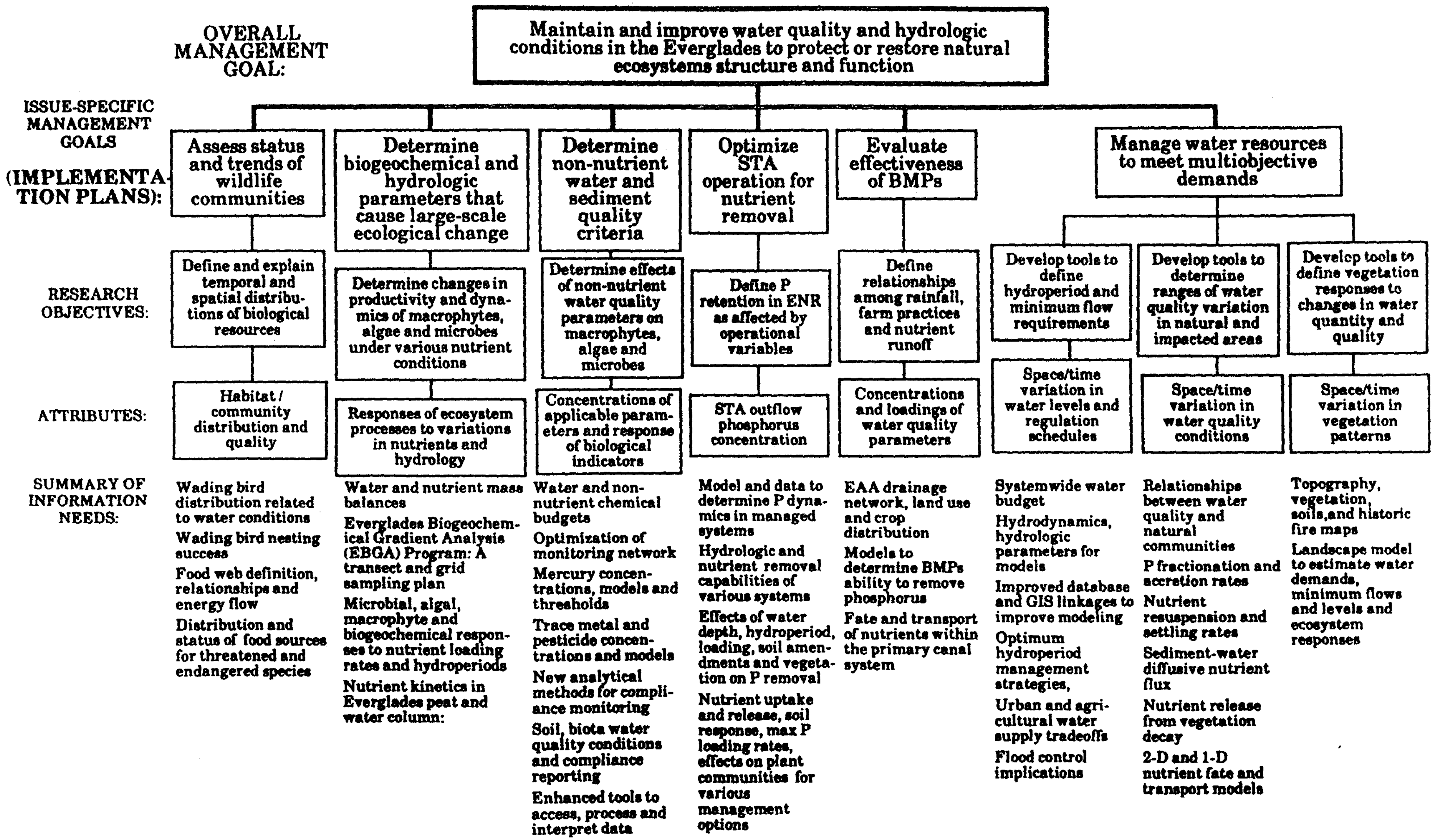
Six major Everglades management objectives and research programs to address these have been identified. These objectives and associated attributes and information needs are summarized in **Figure 2.** Each management objective will be addressed by one of six Resarch Implementation plansas follows:

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	Year 2	Year 3	Year 4	Year 5
	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	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