Appendix 12-1: Coastal Ecosystems Division Science Plan

Edited by Peter Doering

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Vision Statement: To be the world's premier water resource agency

Mission Statement: To manage and protect water resources of the region by balancing and improving water quality, flood control, natural systems and water supply

Coastal Ecosystems Division

Vision Statement: To be recognized leaders in applied coastal research and management

Mission Statement:

- To design, prioritize, and implement interdisciplinary research to address key issues of natural resource protection, management, and rehabilitation in the estuaries of South Florida
- To provide information and recommendations to decision makers, based on research results, to ensure the protection, enhancement, and restoration of regionally important ecosystems and for evaluating tradeoffs among conflicting needs of nature and society
- To disseminate the products of research through publications in peer-reviewed scientific literature

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INTRODUCTION

The Coastal Ecosystems Division (CED) conducts applied research to inform management of the nine systems that surround the coastline of the South Florida Water Management District (SFWMD or District). These systems comprise the elements of the District's Coastal Watershed Program. They are: Southern Indian River Lagoon, St. Lucie River and Estuary, Loxahatchee River and Estuary, Lake Worth Lagoon, Biscayne Bay, Southern Charlotte Harbor, Caloosahatchee River and Estuary, Estero Bay, and the Naples-Rookery Bay–Ten Thousand Islands region. The boundaries of these systems include not only the coastal receiving water body but also the associated watershed.

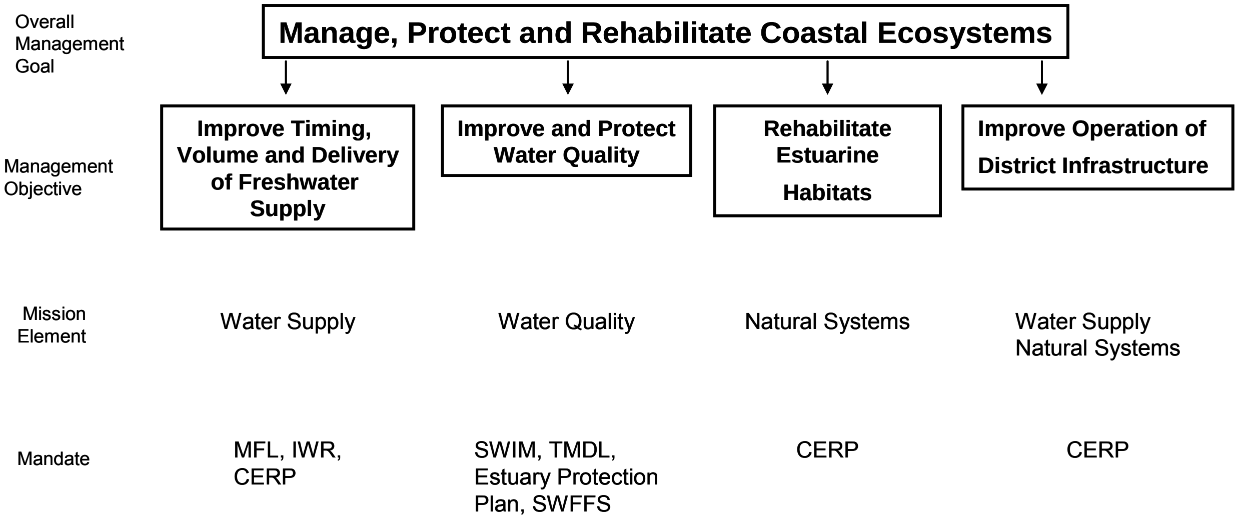
The Coastal Ecosystems Research Plan serves several purposes: (1) to highlight the links between applied research and water management, (2) to provide a conceptual scientific context for conducting relevant applied research in coastal areas, (3) to present a general research strategy applicable to all coastal systems, and (4) to summarize near-term research activities in the nine systems.

Conducting applied research that addresses management concerns in so many systems presents a challenge, made more difficult by limited resources. To maintain the critical linkage between applied research and the mission of the SFWMD, legislative mandates and District policy, the process employed to formulate the goals and objectives of the Coastal Ecosystems Division Research Plan borrows from the hierarchical decision analysis approach (Reckhow, 1994a; 1994b; Reckhow et al., 1997). The decision analysis hierarchy begins with (1) an overall management goal, and is followed by (2) issue-specific management objectives required to attain the overall goal. The issue-specific management goals address major ecological problems in estuaries that are related to specific elements of the District's mission and specific legislative mandates (see **Figure 1**). The intent of using decision analysis is to focus research on issues that the District can address through water management.

In keeping with the decision analysis process, the plan describes a generalized applied research strategy, intended to achieve management objectives and provide relevant, defendable information to decision makers in a timely and cost-efficient manner. The strategy combines an integrated modeling approach to predict fate and transport of pollutants and their impacts on the ecosystems (Chesapeake Bay Program and IAN, 2005) with the Valued Ecosystem Component approach developed by the United States Environmental Protection Agency (USEPA, 1987). This Integrated Modeling and Resource Assessment Framework can (1) be applied to any coastal water body and its watershed at different levels of complexity, (2) serve as a guide to identify information requirements and formulate research plans for each individual water body, (3) fulfill applied research objectives, and (4) provide the information required for sound, science-based management. This integrated modeling framework has been implemented and has proven to be an effective approach for coastal ecosystems restoration efforts undertaken by the Coastal Ecosystems Division (e.g., Wan et al., 2002, 2006).

The research plan is divided into several sections. The *Background* section that follows describes a conceptual model of the influence of fresh water on coastal/estuarine ecosystems. This conceptual model establishes a scientific context for addressing major estuarine problems, and a scientific foundation for the applied research strategy.

A discussion of the major environmental problems facing estuaries in South Florida and the management objectives to address them follows. Finally, the Integrated Modeling and Resource Assessment Framework and its application are discussed. The plan ends with a series of individual research inventories for each water body. This is the first time that such information from all systems has been brought together in one place. Over the next few years, these inventories will be expanded into fully developed strategic science plans that are linked to management objectives for each system.



Overall Management Goal	Manage, Protect and Rehabilitate Coastal Ecosystems			
Management Objective	Improve Timing, Volume and Delivery of Freshwater Supply	Improve and Protect Water Quality	Rehabilitate Estuarine Habitats	Improve Operation of District Infrastructure
Mission Element	Water Supply	Water Quality	Natural Systems	Water Supply Natural Systems
Mandate	MFL, IWR, CERP	SWIM, TMDL, Estuary Protection Plan, SWFFS	CERP	CERP

Figure 1. Management goal and objectives for coastal ecosystems and their relation to the mission of the SFWMD and other mandates.

Legend:

MFL – Minimum Flow and Level
IWR – Initial Water Reservation
CERP – Comprehensive Everglades Restoration Plan
SWIM – Surface Water Improvement and management
TMDL – Total Maximum Daily Load
SWFFS – Southwest Florida Feasibility Study

BACKGROUND

Estuaries surround the jurisdictional boundaries of the District and serve several, often conflicting, societal uses. Estuaries are among the most productive ecosystems on earth and support both commercial and recreational fisheries. As much as 90 percent of the annual Gulf of Mexico fisheries value can be attributed to estuarine-dependent species. Approximately 60 to 90 percent of the Atlantic Ocean species spend a portion of their life cycle in estuaries (Seaman, 1988). The vast majority of South Florida's population is located along the coast, and perhaps for aesthetic reasons, the shores of estuaries are desirable places to live. Estuaries are important waterways for commercial transport and often serve as the direct recipient of processed industrial and municipal waste. Estuaries also provide flood protection, draining rainfall runoff from residential and agricultural land. Therefore, Florida's economy, quality of life, and environmental well-being are dependent on healthy estuaries.

By definition, an estuary is a body of water in which fresh water from the land mixes with and measurably dilutes seawater (Ketchum, 1951). It is fresh water that defines many of the valued characteristics of estuaries. It supports estuarine productivity and influences both the distribution and abundance of estuarine-dependent organisms. Freshwater inflow also influences water quality. The South Florida Water Management District manages the fresh waters (surface and ground) in a 16-county area. Much of this water ultimately makes its way to the coast, passing through canals and coastal water control structures that are operated by the District and its federal partner, the U.S. Army Corps of Engineers (USACE).

In South Florida, water management practices including flood control, maintaining water supply, appropriating water for irrigation, constructing drainage systems to support agriculture and urban development, implementing best management practices to control export of nutrients and other pollutants, and lake regulation schedules all influence the quantity, quality, and timing of freshwater inflow to estuaries. The District is involved in many of these activities and therefore maintaining a functional estuary by delivering the right amount of water with the right quality at the right time is part of the agency’s mission. The role of the Coastal Ecosystems Division is to (1) determine what constitutes the “right amount,” the “right quality,” and the “right time;” (2) assemble the predictive tools to evaluate the efficacy of management options; and (3) develop performance measures for adaptive management of coastal ecosystems and their attendant infrastructures.

A CONCEPTUAL MODEL

Figure 2 presents a conceptual framework for evaluating the effects of freshwater inflow on estuaries, after Alber (2002). It involves establishing how the characteristics of freshwater inflow (quantity, quality, and timing) influence conditions (salinity, nutrient concentrations and the like) in the estuary, and how these conditions in turn affect different resources (species, communities) or processes (productivity, nutrient cycling) in the estuarine ecosystem.

It is beyond the scope of this research plan to present an exhaustive review of the peer-reviewed science that supports and describes the nature of the links in this conceptual diagram. However, a short review is included for explanatory purposes. This conceptual model illustrates not only how alterations in freshwater inflow will change an estuarine ecosystem, but also provides a road map for management. Identifying the environmental requirements of important estuarine resources leads to a target set of estuarine conditions that can be achieved by managing the quantity, timing, and quality of freshwater inflow to an estuary. The model itself does not specifically address temporal and spatial variability in an estuarine ecosystem. For a positive resource response to result from management of freshwater inflow, the resource itself must be exposed to the flow-dependent set of estuarine conditions that make the positive response possible. In other words, flow management must achieve temporal and spatial overlap (Browder and Moore, 1981) between the resource and estuarine conditions eliciting a positive response from the resource. Although the model begins with freshwater inflow to the estuary, the quantity, timing, and quality of this inflow are determined by events that occur upstream in the watershed (Alber, 2002). Therefore, the conceptual model also tells us where implementation of management actions needs to occur.

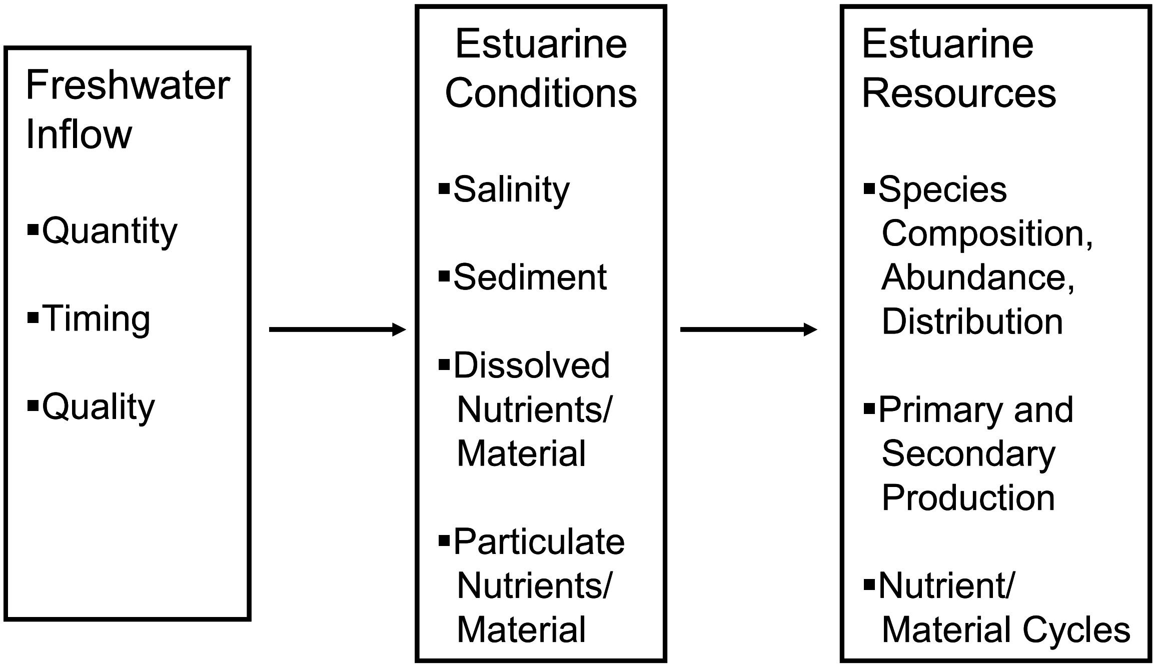


Figure 2. Effects of freshwater inflow on estuaries, after Alber (2002).

Freshwater Inflow

Human activities in the watersheds of coastal ecosystems can significantly alter the quantity, timing, and quality of flows reaching the coast. Dams and upstream water withdrawals can reduce the amount of water reaching an estuary (Nichols et al., 1986). Land use changes, such as deforestation and urbanization, can increase freshwater inflow (Hayward et al., 2006). Timing of inflow can also be altered. Agricultural drainage systems increase the amplitude and rate of stormwater runoff and decrease the interval between when rain enters the watershed and runoff occurs (Hopkinson and Vallino, 1995). An additional effect is to reduce the recharge of groundwater which sustains stream flow during the dry season. As a result, stream flow is reduced or ceases (Hopkinson and Vallino, 1995). The quality of freshwater inflow is also affected by upstream activities such as the application of fertilizer, which can increase the concentration of nitrogen (Boesch, 2002) and deforestation, which can increase nutrient concentrations and turbidity (Bormann et al., 1974).

Estuarine Conditions

Changes in the quantity, timing, and quality of freshwater inflow also affect conditions within the estuary itself. the lack of freshwater inflow results in saltwater intrusion (Doering et al., 2001). Estuarine concentrations of nutrients, sediments, organic matter and pollutants have all been correlated with the rate of freshwater inflow (Alber, 2002). It has also been shown theoretically (Cifuentes et al., 1990) and empirically in the field (Magnien et al., 1992; Doering and Chamberlain, 1999) that changes in the quality of freshwater input are reflected in estuarine receiving waters. Internal rate processes, such as primary productivity and nutrient recycling by sediments, have also been shown to depend on material supplied by rivers and other external sources (e.g., Oviatt et al., 1984; Boynton et al., 1995). Through its influence on water residence time, the magnitude of freshwater input dictates the reactivity of material in an estuary. It can, for example, determine whether an estuary traps or exports land-derived nutrients (Officer, 1980; Nixon et al., 1996; Dettman, 2001). Through its influence on salinity, fresh water affects physical and chemical reactions (flocculation, coagulation) that depend on ionic strength.

Estuarine Resources

Through its influence on estuarine conditions, freshwater inflow also influences biotic resources. Because the magnitude of freshwater input largely determines the magnitude and distribution of salt in an estuary, it also influences biological structure. Historically, salinity is considered to be the environmental variable that primarily controls the performance, composition, distribution, and abundance of estuarine flora and fauna (Emery et al., 1957; Gunter, 1961; Kinne, 1966; Bulger et al., 1993). It is important to note that while these parameters have been correlated with average salinity, the magnitude of salinity variation also may affect biological structure (Montague and Ley, 1993; Emery et al., 1957). Thus, the variability in rate of freshwater discharge that occurs over a given period of time may be as important as the total volume discharged.

Estuaries are characterized by high primary and secondary productivity (Nixon et al., 1986; Nixon 1988). It is generally agreed that freshwater input maintains this production (Fisher et al., 1988; Day et al., 1989; Montanan and Kalke, 1992). This agricultural paradigm regards the nutrients carried to estuaries by freshwater inflows as beneficial, with higher freshwater inflows leading to higher yields of desirable species. Yet the relationship between freshwater input and estuarine productivity is not completely understood (Livingston et al., 1997). While productivity is often positively correlated with the quantity of freshwater discharge, both reductions and increases in discharge can result in reduced productivity (Wilbur, 1992; Livingston et al., 1997; Turner, 2006).

The somewhat muddled response of estuarine productivity to freshwater inflow may be explained by factors other than nutrients. In a recent review of recruitment of fish and other nekton, Petersen (2003) unifies the dynamic-stationary habitat overlap hypothesis of Browder and Moore (1981) with Cushing’s (1990) match/mismatch hypothesis. Peterson (2003) notes that successful recruitment depends first on larvae approaching their physiological optima (salinity, temperature, dissolved oxygen) in the surrounding water (dynamic habitat) and then having available the appropriate habitat structure (e.g., grass bed, sediment type: stationary habitat) for other life requirements. Chief among these other requirements is the overlap between nekton larvae and their prey. Annual variation in temporal and spatial overlap (match/mismatch) is reflected in subsequent recruitment. The dual role of freshwater inflow in positioning larvae with respect to physical habitat and food, and supplying the nutrients to grow the food, is evident here.

Estuarine water quality can determine the viability of estuarine biological communities (Dennison et al., 1993; Stevenson et al., 1993). Perhaps the severest threat to estuarine water quality is eutrophication by nutrient inputs from wastewater treatment facilities, urban and agricultural runoff, and other sources (Gray, 1982, 1992; Kennish, 1992; NRC, 2000). Rivers and canals are often the major conduits of excessive nutrient loads to estuaries. Eutrophication results in altered species composition, reductions in macrophytes and ultimately anaerobic conditions and mass mortality. Harmful algal blooms, outbreaks of fish lesions, and other undesirable events have been associated with excess nutrient loading (NRC, 2000; Cloern, 2001).

This view of nutrients as undesirable pollutants contrasts with the agricultural paradigm. As Kelly (2001) has pointed out, while it is not known what the precise positive limits of fertilization are, the basic requirements for enriching a system to oxygen depletion and mass mortality are known.

Watershed Management

Inherent in Alber's (2002) conceptual diagram, is the watershed's influence on the quantity, timing, and quality of water reaching an estuary. Coastal ecosystems and their watersheds are closely coupled (see Estuaries, Volume 15, No. 5, 1992, dedicated to this subject) and many of the undesirable impacts on coastal ecosystems can be traced to anthropogenic activities in the watershed (Hale et al., 2004; Bilkovic et al., 2006; Stedmon et al., 2006; Hayward et al., 2006). Therefore, strategies to ameliorate or reverse these impacts have emphasized management at the watershed scale. The SFWMD has adopted this approach as evidenced by the Comprehensive Everglades Restoration Plan, and the Lake Okeechobee and Estuary Recovery Plan. These plans all propose to "fix" problematic freshwater inflows to estuaries with engineering solutions implemented in the watershed. A further challenge facing the District is to adaptively manage the operation of the watershed management infrastructure to meet the goal of coastal ecosystem restoration.

PROBLEMS IN SOUTH FLORIDA ESTUARIES

Estuaries in South Florida suffer from (1) disruption of the natural magnitude (excess or lack of) and timing of freshwater input, (2) increasing inputs of pollutants (nutrients, bacteria, toxics, etc.) and sediment, and (3) loss of critical estuarine habitat and biological communities.

DELIVERY

Anthropogenic manipulation of upland hydrology has altered the delivery of fresh water to estuaries within the South Florida Water Management District. Alterations to estuaries themselves have changed the way they respond to freshwater input. Construction of drainage systems in coastal watersheds to accommodate agriculture and urban development has resulted in a loss of storage. During the rainy season, runoff occurs over a shorter duration at higher volumes and peak discharges. In addition, drainage basins have sometimes been enlarged through construction of canals. Artificial connections to Lake Okeechobee are also important for several systems. When the Lake level climbs above a predetermined height, mandatory releases are made to the Caloosahatchee Estuary on the west coast and to the St. Lucie Estuary on the east coast. Smaller releases are sometimes made to the Lake Worth Lagoon, also on the east coast. The hydrodynamics of estuaries themselves has been modified by dredging of navigation channels and permanent inlets to the ocean, removal of oyster bars, and construction of bridges and causeways.

The end result is that the delivery of fresh water to estuaries can vary substantially on seasonal and shorter time scales. During the rainy season, the volume and rate of stormwater runoff can be so high that an entire system is turned fresh. Regulatory releases from Lake Okeechobee only compound this problem. By contrast, agricultural and municipal demands for fresh water during the dry season can severely curtail freshwater discharge, resulting in significant intrusion of ocean water. Compounding this problem has been the placement of water control structures near the heads of estuaries. Because these structures block the upstream mixing of ocean water with fresh water, near-marine salinities can prevail throughout most of the estuary during dry periods. Variability in freshwater inflow causes large variations in estuarine salinity that cause mortality of estuarine organisms (Haunert and Startzman, 1985; Doering et al., 2001).

During the next two decades, implementation of the Comprehensive Everglades Restoration Project, Acceler8, and the Northern Everglades Protection Plan will result in the construction of new infrastructure designed in part to restore a more natural delivery of fresh water to South Florida's estuaries. Meeting the challenge of operating this infrastructure requires a focused evaluation of the manner in which fresh water is delivered to tide.

WATER QUALITY

Both the St. Lucie and Caloosahatchee show signs of over-fertilization with nutrients. The St. Lucie experiences large phytoplankton blooms and periods of hypoxia in its bottom waters (Chamberlain and Hayward, 1996; Graves and Strom, 1992). Similarly, in the late 1970s, the Florida Department of Environmental Regulation determined that the Caloosahatchee had reached its nutrient loading limits (DeGrove, 1981; DeGrove and Nearhoof, 1987; Baker, 1990) owing to elevated chlorophyll *a* (Chl *a*) and depressed oxygen levels. National Oceanic and Atmospheric Administration's (NOAA's) National Estuarine Eutrophication Assessment identified the Caloosahatchee as one of 44 estuaries nationwide that exhibited a high expression of the symptoms of eutrophication (Bricker et al., 1999). Recently, massive blooms of red drift algae have been attributed to escalating eutrophication of the Caloosahatchee (LaPointe and

Bedford, 2006). Nutrient concentrations in the St. Lucie Estuary have also been consistently high in recent years (Chamberlain and Hayward, 1996; Doering, 1996). Sediments in the St. Lucie have been shown to contain heavy metals at levels potentially harmful to fish and benthic macro-invertebrate communities (Haunert, 1988; Thompson et al., 2001). Algal blooms have occurred in the St. Lucie Estuary during recent years when runoff volume is high.

Canal discharges to coastal systems can also result in excessive sedimentation. Large areas of muck sediments have accumulated in Lake Worth Lagoon, especially in the region influenced by the outflow from the C-51 canal (Lietz and Debiak, 2005). Sediment deposits, although patchy in distribution, may be greater than 1 foot in depth, with accumulation rates ranging from 0.1 to 0.9 cm/yr over the last 20 years. These deposits prevent seagrasses and oysters from colonizing the seafloor. Resuspension of these fine-grained sediments also increases light attenuation, further inhibiting seagrasses.

ESTUARINE HABITAT

Habitat is the kind of environment in which an organism or biological community lives. The ecological "bottom line" is that without appropriate habitat, a species will cease to exist (Jowett, 1997). A habitat can be inanimate, such as a field of boulders, a mud flat, or a low salinity, open water zone (oligohaline zone). On the other hand, habitat also can be living, such as a seagrass meadow. Owing to the pattern of glaciation, Florida's coastline is flat, with little topographic relief on either large or small spatial scales. Estuarine habitats that have physical relief tend to be biological and include mangrove prop roots, grass beds, and oyster bars. It is important to note that these habitats are distributed along the estuarine salinity gradient with different habitat forming species occupying different portions of the salinity gradient. The success of these habitat-forming species is thus critical to the success of the many other species that utilize the habitats and the salinity zones in which they occur.

Urban development, dredging, and changing drainage patterns have affected estuarine shoreline and in-water habitat. For example, Harris et al., (1983) documented loss of mangrove and seagrass habitat in the Lake Worth Lagoon and the Caloosahatchee Estuary. Prior to 1960, submerged aquatic vegetation extended far upstream in the St. Lucie Estuary (Phillips, 1961). Today its distribution is confined to the lower estuary near the clearer waters of the Indian River Lagoon (Woodward Clyde, 1999). The increased accumulation of unconsolidated, contaminated sediments has partly contributed to the loss of the oyster and seagrass beds in the St. Lucie Estuary. In the Loxahatchee River, progressive saltwater intrusion caused by reduced freshwater flows and maintenance of a permanent connection with the ocean has changed up to two river miles of flood plain swamp into mangrove forest (SFWMD, 2006).

MANAGEMENT OBJECTIVES

The overall goal of estuarine management, to "manage, protect and rehabilitate coastal ecosystems," follows from the District mission to manage and protect water resources (**Figure 1**). The four management objectives required to attain that goal are based on three major elements of the District mission: water quality, water supply, and natural systems, as they apply to coastal ecosystems. These management objectives supported by various mandates, address major problems facing coastal ecosystems in South Florida today: altered delivery of fresh water, water quality, and loss of habitat. The four management objectives are discussed in detail below.

IMPROVE TIMING, VOLUME AND DELIVERY OF FRESH WATER

The goals of applied research supporting the management objective, to "improve timing, volume and delivery of freshwater supply," are to (1) quantify the responses of estuarine resources and processes to changes in these key characteristics of freshwater inflow, (2) establish quantities of fresh water required to provide various levels of environmental protection, and (3) develop predictive tools that allow scientifically defendable evaluation of management options to supply these quantities of water.

State and federal mandates require the District to identify up to three different quantities of fresh water that can be delivered to an estuary. Required by state law (Chapter 373, Florida Statutes), Minimum Flows and Levels protect water resources from "significant harm,, which is uniquely defined by the Governing Board of each water management district. Required by CERP, initial water reservations are defined as the amount of water currently being delivered to a system that protects fish and wildlife. Finally, a restoration flow is the quantity of water required to enhance or return aquatic resources and/or functions to some target state (e.g., restore 900 acres of oyster beds in the St. Lucie Estuary).

IMPROVE OPERATION OF DISTRICT INFRASTRUCTURE

The management objective to "improve operation of District infrastructure" has two components. Coastal Ecosystem Division Staff provides weekly input to operational decisions based on the status of the Caloosahatchee and St. Lucie estuaries. While best professional judgment comprises most of this input, forecasting tools that will provide probability-based predictions of future estuarine salinity and ecological response are under development. This will allow water managers to more accurately anticipate and perhaps avoid exceedances of salinity criteria for minimum flows and levels, and large releases that may damage marine resources by adjusting day-to-day management of the regional system.

The second component of this objective involves applying science to the operational rules and protocols of District infrastructure. The District is constructing new reservoirs, stormwater treatment areas, and aquifer storage and retrieval wells in an effort to improve both environmental and human water supply. Successful operation of this new infrastructure will be critical to achieving environmental goals in coastal ecosystems. Central to successful operation is the environmentally compatible delivery of fresh water to downstream estuarine and marine systems. The Coastal Ecosystems Division studies the operation of small systems, such as the Ten Mile Creek Facility, that may serve as a model for larger projects being built in the Caloosahatchee and St. Lucie River basins. The aim is to (1) evaluate different discharge scenarios or regimes on the physics, water quality, and biology of the downstream estuary through manipulative field experiments and (2) to use this information to create predictive tools to evaluate and develop environmentally sustainable operational protocols.

Defendable, science based estimates of these quantities and rules for delivering them are useful to the District in consumptive use permitting, formulation of regulation schedules, operation of the regional water management system, and the physical design and operation of facilities intended to provide human and environmental water supply. Facilities, including reservoirs, storm water treatment areas, and aquifer storage and retrieval wells are being constructed by as part of CERP, Acceler8, the Lake Okeechobee and Estuary Recovery Plan and the Northern Everglades Protection Plan.

IMPROVE AND PROTECT WATER QUALITY

The management objective "Improve and Protect Water Quality" supports the District's water quality mission element. To address water quality issues, the Florida legislature enacted the Surface Water Improvement and Management (SWIM) Act in 1987, directing water management districts, in cooperation with state and local agencies, to design and implement plans to improve many aquatic systems in Florida, including estuaries. A state water policy (Chapter 62-40, Florida Administrative Code) also was enacted, requiring water management districts to establish regional stormwater management policies for watersheds by determining pollutant load reduction goals (PLRGs) that will restore and preserve the beneficial uses of receiving waters. The Florida Watershed Restoration Act (TMDL Bill) (SB 2282) requires The Florida Department of Environmental Protection (FDEP) to establish total maximum daily loads (TMDLs) for certain water bodies. The legislation requires that the FDEP coordinate with water management districts in establishing TMDLs and PLRGs. The Northern Everglades Protection Act also mandates water quality improvement in the Caloosahatchee and St. Lucie estuaries. One charge of the Southwest Florida Feasibility Study is to address water quality issues in the coastal water bodies of the lower west coast of Florida.

The science supporting this objective has, until recently, concentrated on evaluating water quality status, trends (Chamberlain and Hayward, 1996; Doering, 1996; Doering and Chamberlain, 1999) and loadings from the watershed (Graves et al., 2004). As signs of cultural eutrophication have become more apparent, more attention has been focused on this issue, and studies of limiting nutrients, nutrient cycling, and the development of water quality targets (Crean et al., in press), indicators (Doering et al., 2006), and water quality models (Applied Environmental Engineering, 2004) have begun.

REHABILITATE ESTUARINE HABITATS

As with other management objectives, "Rehabilitate Estuarine Habitats" supports a key District mission element: natural systems. Habitat loss in South Florida occurs for many reasons including management of freshwater inflow to coastal ecosystems, dredging of navigation channels, prop scars from boats, shoreline development, storms, and mining of oyster shell for road material. The Coastal Ecosystems Division supports restoration of estuarine habitat by (1) funding "on the ground" restoration efforts such as mangrove plantings, construction of oyster reefs, and conducting trial plantings of submerged aquatic vegetation (SAV) (2) assessing the natural population's ability to repopulate, (e.g., seed bank studies of SAV) (3) using a resource-based approach to establishing water quantity and quality targets (see the *Valued Ecosystem Component* section). The goal of applied research is to discover how water management practices may be adjusted to preserve, protect, and/or enhance key estuarine habitats.

INTEGRATED MODELING AND ASSESSMENT FRAMEWORK

The general research strategy used to meet these management objectives combines the resource-based Valued Ecosystem Component approach with an integrated watershed–estuarine modeling approach. The large spatial scales associated with management of coastal ecosystems renders direct experimentation at the watershed level difficult and expensive. Controlled, real-world experiments that address management problems have been conducted on the watershed level (e.g., Hubbard Brook Experimental Forest, Bormann et al., 1974). However, a more recent approach has been to use integrated or linked models to simulate the effects of changes in population, land use or management practices in the watershed on estuarine physics, chemistry, and ecology (Chesapeake Bay Program and IAN, 2005; Wan et al., 2002; 2006).

The integrated modeling approach diagrammed in **Figure 3** below formalizes Alber's (2002) conceptual model (**Figure 2**) into a predictive tool. The watershed model estimates the quantity, timing, and quality of freshwater inflow to the estuary. The estuarine hydrodynamic, sediment transport and water quality models, in turn, simulate the estuarine conditions of the conceptual model. Finally, the ecological models simulate the responses of estuarine resources and processes to the estuarine conditions. The District has been using this approach for several years in the technical documentation required for its Minimum Flows and Levels Program, and in CERP-related studies, both for feasibility studies (Indian River Lagoon South, Southwest Florida Feasibility Study) and at the project level (C-43 basin reservoir).

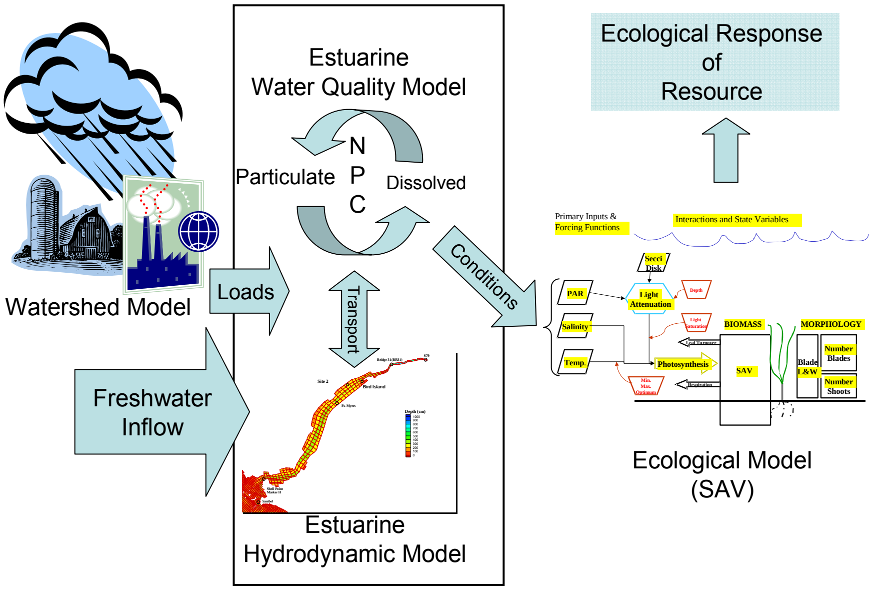


Figure 3. Integrated Modeling Framework.

VALUED ECOSYSTEM COMPONENT

The Valued Ecosystem Component (VEC) approach was developed by the U.S. Environmental Protection Agency (USEPA) (1987) as part of its National Estuary Program. The definition of a VEC can be fairly broad: “Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process.” Importance may be determined on the basis of scientific concern or based on cultural values (SFWMD, 2001). The Coastal Ecosystems Division uses the VEC approach to identify key estuarine resources that will be the object of the ecological models mentioned above. Therefore, the approach has been modified to focus on providing critical estuarine habitat. In many instances, that habitat is biological and typified by one or more prominent species (Doering et al., 2002, Chamberlain and Doering, 1998, SFWMD, 2006). In other cases, the habitat may be physical, such as an open water oligohaline zone (SFWMD, 2002). Enhancing and maintaining these biological and physical habitats should lead to a generally healthy and diverse ecosystem.

Examples of biological habitat are oyster bars and grass beds, with prominent species being the American oyster, *Crassostrea virginica* and the SAVs, *Vallisneria americana*, *Halodule wrightii*, and *Thalassia testudinum*. Implicit in this approach is the assumption that maintaining or enhancing prominent species will, in turn, enhance the entire community. Comparisons of the habitat value of re-colonized and transplanted SAV beds with naturally existing beds provide support for this assumption (Brown-Petersen et al., 1993; Fonseca et al., 1990). This approach also recognizes that, in practice, an estuary cannot be managed to furnish ideal environmental conditions for all species that human users might want. The focus on dominant estuarine habitats represents a feasible alternative that has a chance for success.

The VEC forms the foundation of the integrated modeling and assessment framework. The freshwater quantity and quality required by the VEC, ultimately determine the solution implemented in the upstream watershed, whether it be construction of new infrastructure, changes in operational protocols, or implementation of best management practices. The approach furnishes both a goal, defined by VEC requirements, and a predictive tool for evaluation of alternative solutions.

APPLICATION

Since the requirements of the VEC ultimately prescribe the solution, it is important to understand how the approach can be applied to different problems. Suppose a species of SAV is used for a VEC. The response of the VEC to salinity in the estuary is examined to determine the flow quantity. In practice, the location of the SAV in the estuary and the level of salinity-dependent performance of SAV determine the magnitude of flow required (Doering et al., 2002). For example, at the same location a salinity required for survival might require a different flow than that required to produce salinity appropriate for moderate growth. Similarly, maintaining the same salinity at two different locations will require different flows. Therefore, a flow required to protect against significant harm will be less than that required for restoration. The advantage of using a resource-based approach is that a level of resource performance (e.g., survival) can be associated with a level of protection (e.g., from significant harm). The hydrodynamic model can be used to determine the amount of fresh water required to achieve the salinity associated with a given level of resource performance and hence regulatory protection. The watershed model can be used to determine if that amount of water is currently being supplied. In concert, the watershed model, the hydrodynamic salinity model, and the ecological SAV model can be used to evaluate different alternatives to supply the appropriate water quantity at the appropriate times. In cases where a storage reservoir is required as a restoration option, a reservoir optimization model can be used to size the reservoir and produce the needed operation rules to meet the target flow distribution requirements (Wan et al., 2006).

It is also important to define “model.” The models employed in the Integrated Modeling and Resource Assessment Framework can range from simple to complex. On the simple end of the spectrum are statistical, empirical relationships; while on the complex end are deterministic, numerical models (see **Table 1**). **Table 1** provides examples of simple, intermediate, and complex linked models chains that might be used to address water quantity issues. The agency’s water quality modeling efforts are just beginning and a similar table will be formulated for water quality issues with gained experience.

Table 1. Examples of different levels of complexity of linked models employed to address water quantity issues in an estuary.

	Models	Watershed	Estuarine	Ecological
Simple	Empirical (statistical)	Rainfall-Runoff Relationship	Salinity-Runoff Relationship	Salinity-Abundance Curve
Intermediate	Lumped	CREAM-WT	Steady State Box Model (e.g., Officer 1980)	Habitat Suitability Model
Complex	Spatially distributed, Deterministic, Numerical	WaSh, MIKE-SHE	RAM, EFDC, CH3D	Spatially Explicit Population Dynamics Model

The advantages of allowing application of models with differing levels of complexity are several. First, the complexity of the effort can be tailored to the complexity of the problems that a given estuary has. This approach allows for use of best available information often called for in legislative mandates. When information is lacking, data gathering efforts can be focused to fill gaps that are required for successful application of the models. The level of model complexity can be adjusted to provide the level of certainty required in decision making and water management.

Acknowledging different levels of model complexity also means that application of the framework in any one system can be an iterative, evolutionary process. For example, synoptic surveys of estuarine salinity would support a steady-state box model (Officer, 1980), but not a time-varying hydrodynamic model, such as CH3D (Sheng, 1987). As appropriate data become available, the steady-state box model could be “upgraded” to a more fully hydrodynamic model. Similarly, as more data become available, VEC models could be recast to include more variables, or existing models can be periodically re-validated. The long-term application of the Integrated Modeling and Resource Assessment Framework includes a feedback loop between the level of understanding of a given system and the models used to simulate it. The division’s understanding of coastal ecosystems depends on research and monitoring. As the level of understanding and ability to describe coastal ecosystems improves so can the ability of District models to predict responses.

The District has been applying the integrated model approach to coastal and estuarine water quantity problems for several years. The following three examples illustrate how the approach has been used to solve management problems using models of differing complexity. They are the Caloosahatchee River and Estuary Minimum Flow Level, the Southern Indian River Lagoon Feasibility Study, and the Restoration Plan for the Northwest Fork of the Loxahatchee River. All these examples illustrate how the Integrated Modeling and Resource Assessment Framework achieves management objectives to improve the timing, volume and delivery of freshwater inflow, improve operation of District infrastructure, and rehabilitate estuarine habitats.

The Caloosahatchee River and Estuary Minimum Flow Level

The Caloosahatchee Estuary is located on the west coast of Florida (see the Water Body Science Plan). Its major source of water is the Caloosahatchee River (C-43). The river and estuary are separated by the Franklin Lock and Dam (S-79), a water control structure. During the dry season, the estuary receives very little inflow from the Caloosahatchee River and salinity can reach 18–20 ppt at the structure, truncating the salinity gradient and eliminating the oligohaline zone. The salt-tolerant freshwater species of SAV, *Vallisneria americana*, provides important habitat in the upper estuary when salinity conditions are tolerable. *Vallisneria* was chosen as the VEC for the upper estuary. The Caloosahatchee River and Estuary Minimum Flow Level is based on supplying enough freshwater discharge to the estuary at S-79 to maintain salinity low enough to avoid salinity-related mortality of *Vallisneria*. To estimate the amount of water required, the technical documentation of the Caloosahatchee River and Estuary MFL (SFWMD, 2000) linked runoff output from the South Florida Water Management Model (deterministic, numerical) with a statistical regression model relating discharge at S-79 to salinity in the estuary. This was, in turn, linked with a simple empirical statistical model relating salinity concentration to mortality of *Vallisneria*. The regression model suggested that a discharge of 300 cfs at S-79 was required to maintain a tolerable salinity (< 10 ppt) in the upper estuary.

This MFL was revisited in 2003 (SFWMD, 2003). By that time, a time-dependent, three-dimensional hydrodynamic model of the Caloosahatchee Estuary had been calibrated and verified. Output from a watershed model provided freshwater input from the estuarine tidal basin, downstream of S-79. The CH3D (Sheng, 1987) hydrodynamic/salinity model suggested that a total inflow of about 450 cfs was required to maintain a salinity less than 10 ppt in the upper estuary. Comparison of discharges at S-79 with those from the downstream tidal basin revealed that, on average, when discharges were about 300 cfs at S-79, an additional 150–200 cfs were discharged from the tidal basin. During drier times, discharge from the tidal basin decreases and 300 cfs discharged at S-79 does not maintain salinity below 10 ppt. This new critical dry-season flow (450 cfs) was incorporated into the design of a CERP reservoir in the Caloosahatchee River watershed and into a new regulation schedule managing water levels in Lake Okeechobee.

The Caloosahatchee experience illustrates the benefits of the iterative application of the integrated modeling approach. The original regression approach that related discharge at S-79 to salinity in the downstream estuary did not explicitly include a term for tidal basin discharge. Instead this was implicitly reflected in the salinity data. New data incorporated into more sophisticated models allowed a quantitative partitioning of freshwater inflow between the river basin and tidal estuarine basin. This new understanding was subsequently incorporated into the adaptive management process.

The Southern Indian River Lagoon Feasibility Study

The ecosystem of the Southern Indian River Lagoon including the St. Lucie Estuary, located on the east coast of South Florida (see the water body science plan), has been greatly influenced by the altered delivery of freshwater inflow due to land use change and development of drainage canals in the tributary watershed. Previous biological research conducted by the SFWMD (e.g., Haunert and Startzman, 1985) established that a mesohaline environment is critical to the health of salinity-sensitive biota including oysters, submerged aquatic vegetation, and juvenile and marine fish and shellfish. The feasibility study focused on hydrologic restoration to the pre-drained or natural hydrologic characteristics in the watershed to aid the recovery and protection of salinity-sensitive biota in the estuary. To achieve this goal, a suite of models dealing with watershed hydrology, reservoir optimization, estuary salinity, and oyster stress was applied. The RMA model was used to simulate estuary hydrodynamic and salinity, and the results showed that unfavorable salinity conditions occurs once watershed inflows exceeds 2,000 to 3,000 cfs. The

Natural Systems Model, which simulates the hydrologic response of the pre-drained watershed to recent climatic conditions, delineated the acceptable exceedance of the flow range. Results of the Natural Systems Model were used as the basis for establishing the hydrologic restoration target, sizing reservoirs, and justifying flow transfers between basins within the watershed. The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the hydrology of the present and future conditions. A genetic algorithm-based optimization model (OPTI), was used to size the storage reservoirs and generate operational rules that govern water release to the St. Lucie Estuary. Finally, an oyster stress model was used to develop a numerical performance measure to evaluate the effectiveness of the project on estuarine ecosystem restoration.

Restoration Plan for the Northwest Fork of the Loxahatchee River

The most recent of the three examples is the Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD, 2006). The Northwest Fork of the Loxahatchee River (see the water body science plan) has lost freshwater habitat due to saltwater intrusion, caused in part by opening of the Jupiter Inlet and construction of C-18 canal for drainage and flood protection. Formulation and evaluation of alternative restoration flow scenarios were based on the successful application of hydrological and salinity models. These models were a watershed hydrological model (WaSh) that simulated long-term freshwater inflows, a two-dimensional estuarine, hydrodynamic and salinity model (RMA) that simulated short-term influences in tributary inflows and tide on estuarine salinity, and a long-term salinity management model (LSMM), a regression model) developed from the RMA results capable of predicting daily salinity in the estuary for the period of record used in the watershed model. VECs were chosen for different portions of the system: floodplain vegetation for the freshwater portion; and oysters, seagrasses, and fish larvae for the saline end of the system. Output from these models was used to evaluate ecosystem responses of these VECs to varying restoration flow scenarios using hydrologic performance measures and salinity tolerance for the freshwater floodplain and salinity-based habitat suitability models for estuarine fauna. The linked models estimated freshwater inflows that would push the salt wedge downstream about 1.5 river miles, allowing for restoration of freshwater floodplain habitat without harming estuarine resources in the saline reaches of the river. The plan not only addressed the water quantity issue, but, using seasonal requirements of the VEC, also went on to suggest a time-varying seasonal distribution of freshwater inflow that could serve as a technical basis for proposed, new infrastructure.

Critical Nitrogen Loads to the Caloosahatchee Estuary

A simple set of “linked” empirical, least-squares regressions were used to calculate a threshold for total nitrogen loading at the Franklin Lock and Dam (S-79) at the head of the Caloosahatchee Estuary (Doering and Chamberlain, 2005). The first equation related the light attenuation coefficient to the concentration of chlorophyll *a* in San Carlos Bay; the second related nitrogen loading to the estuary at S-79 to the concentration of chlorophyll *a* in San Carlos Bay. The concentration of chlorophyll *a* required to allow sufficient light penetration (25 percent of surface) for seagrass growth to a depth of 1.5 meters was calculated. This chlorophyll *a* value (3.2 µg/L) was associated with a 30-day total nitrogen load of 172 metric tons (mt) (2,062 mt/year) at S-79.

No numeric water quality models for the Caloosahatchee exist. This example illustrates how water quality issues can be addressed using simple empirical statistical models.

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SUMMARY OF COASTAL ECOSYSTEM MODELS

The following tables (**Tables 2–5**) provide a summary of the models that the Coastal Ecosystems Division has applied in SFWMD estuaries. Watershed, hydrodynamic, and ecological models are not available for all systems. Some systems, such as the St. Lucie system, are "model rich," while no models are available yet for others, such as Naples Bay or Lake Worth Lagoon. Reflecting expertise within the division, the production of hydrodynamic models has been greater than that of watershed, water quality, or ecological models. The recent emphasis on the St. Lucie and Caloosahatchee estuaries, as part of the Northern Everglades Initiative, suggests that the integrated modeling and assessment framework will mature sooner in these systems than in others.

Table 2. Coastal Ecosystems Division: Estuary and Watershed Models – Biscayne Bay and Florida Bay.

Model Category	Model	Model Domain	Main Outputs	Past Applications	Future Applications	Model Calibration/Application Period
Estuarine Hydrodynamic Model	RMA-10 (TABS-MDS)	Biscayne Bay	Water level, flow velocity and salinity	Biscayne Bay MFLs and CERP Project		Calibration 1997-1998; application: four selected dry/wet and regular years
Estuarine Mass balance: dynamic, spatially explicit	FATHOM	Florida Bay	Average monthly salinity in 44 sub-basins, basin residence times	Florida Bay MFL		

Table 3. Coastal Ecosystems Division: Estuary and Watershed Models – Loxahatchee River and Watershed.

Model Category	Model	Model Domain	Main Outputs	Past Applications	Future Applications	Model Calibration/ Application Period
Watershed hydrology and water quality model	WaSh	Loxahatchee River Watershed	Flow, stage	2003-2006: Restoration Plan for the Northwest Fork of the Loxahatchee River	NPB CERP RECOVER, NW Fork Loxahatchee River Restoration Plan	1965-2005
Estuarine Receiving water hydrodynamics, salinity and sediment transport	RMA	Loxahatchee River and Estuary	Water level, flow velocity, salinity	2000-2003 Lox MFL	NPB CERP RECOVER, NW Fork Loxahatchee River Restoration Plan	2000-2004
Estuarine Hydrodynamic/ salinity	CH3D	Loxahatchee River and Estuary	Water level, flow velocity, salinity	2004-2006 Evaluation of saltwater barrier for Lox Restoration Study		2003-2004
Estuarine Flow – salinity management model for long-term predictions	LSMM	Loxahatchee River and Estuary	Salinity and water demand for salinity management	2003-2006: Restoration Plan for the Northwest Fork of the Loxahatchee River	NPB CERP RECOVER, NW Fork Loxahatchee River Restoration Plan	1965-2005
Three-dimensional integrated surface/ground water model for simulation of both river/estuary and floodplain and interaction between surface and groundwater	3DISG	Loxahatchee River and its floodplain	Water level of surface and groundwater, flow velocity, seepage and salinity	Preliminary calibration completed for surface water component, calibration for groundwater ongoing	NPB CERP RECOVER, NW Fork Loxahatchee River Restoration Plan	December 2003, May 2004

Table 4. Coastal Ecosystems Division: Estuary and Watershed Models – Caloosahatchee Estuary, Estero Bay.

Model Category	Model	Model Domain	Main Outputs	Past Applications	Future Applications	Model Calibration/ Application Period
Estuary Hydrodynamic model	CH3D	Caloosahatchee Estuary and Estero Bay	Salinity at each grid cell with 30-minutes interval	C43 Phase I (2005)	C43 Reservoir Phase II	2000-2004
Estuarine Regression model		Caloosahatchee Estuary and Estero Bay	Daily averaged salinity at certain locations	C43 Phase I (2005)	Southwest Florida Feasibility Study (SWFFS)	
Numerical: Ecological/ SAV	Vela	Caloosahatchee Estuary	*Vallisneria americana* shoot density, blade density and biomass	Caloosahatchee River MFL update (2003) and C43 Phase I (2005)	Salinity Position Analysis associated with the operation of Lake Okeechobee	1991-2005
Estuarine Spreadsheet: regression equation-based		Caloosahatchee Estuary/ St. Lucie	Vertically averaged daily salinity at specified locations	CE MFL update (2003): CE Legal Sources (2003): operations-misc.	Hypothesis testing in CE/ Estuarine Position Analysis	Calibration 1998-2002; Application 1965-2000

Table 5. Coastal Ecosystems Division: Estuary and Watershed Models – St. Lucie Estuary.

Model Category	Model	Model Domain	Main Outputs	Past Applications	Future Applications	Model Calibration/Application Period
Watershed model	WaSh	St. Lucie River Watershed	Flow, stage, water quality	CERP IRL PIR,	Ten Mile Creek, North Fork restoration	1965-2005
Estuarine hydro-dynamics model	RMA	SLE/IRL	Water level, flow velocity, salinity	SLE MFL, TMDL		1997-2000 and partly 2002
Estuarine hydrodynamic model and regression	LSMM	SLE/IRL	Salinity and water demand for salinity management	1998 – 2000: SLE/IRL CERP PIR 1999 – pres. System Operations such as Lake Okeechobee releases		1965-2005
Estuarine Hydro-dynamic, sediment transport and water quality model	EFDC	St. Lucie Estuary	Water level, salinity, velocity, TSS, nutrient, Chl *a*, DO	Model calibration and multiple year WQ simulations		Calibrated for 1999 and 2000
Estuarine Hydrodynamic model	CH3D	St. Lucie Estuary	Water level, salinity, velocity		TMC adaptive management, SLE restoration	Multiple-year simulation (1997-2005)
Estuarine Water quality model	Stand-alone WQ model	St. Lucie Estuary	Nutrient, Chl *a*, DO, TSS		TMC adaptive management, SLE restoration	Multiple-year simulation (1999-2003)
Optimization model for system planning and operation	OPTI	St. Lucie watershed and estuary	Reservoir and STA design parameters such as storage volume	IRL PIR (CERP)	TMC adaptive management, SLE restoration	1965-2000
Estuarine Spreadsheet: regression equation-based		St. Lucie Estuary	Vertically averaged daily salinity at specified locations	operations, lake schedule alternative testing(2006)		1965-2000
Ecological Oyster			Spreadsheet model, daily time step of oyster stress/salinity	IRL PIR	TMC adaptive management, SLE restoration	1965-2000

PROGRAM INVENTORIES AND PLANNED ACTIVITIES

In the following section, brief science plans for specific water bodies are presented. These are not meant to be exhaustive or highly detailed, but only to provide some background and an outline of future direction. The water bodies will be ranked in accordance with the District's priorities and detailed plans will be developed over the next few years. Again, because of the Northern Everglades Initiative, it is expected that the St. Lucie and Caloosahatchee estuaries will be given the highest priority.

ST. LUCIE ESTUARY SCIENCE INVENTORY

Introduction

The St. Lucie Estuary (SLE) is a relatively large brackish water body on the east-central coast of Florida, in Martin and St. Lucie counties, and is a primary tributary to the Southern Indian River Lagoon (SIRL). Most of the watershed drains into the North and South Forks (6.4 square miles) that converge and flow to the middle estuary (4.7 square miles) that extends east for approximately 5 miles to the Indian River Lagoon (IRL) and the Atlantic Ocean at the St. Lucie Inlet.

The SLE and its watershed have been highly altered to accommodate human development. During recent history, the freshwater St. Lucie River was exposed to ocean waters only when large storms caused ephemeral passes in the protective barrier islands. In 1892, however, the St. Lucie Inlet was dug and maintained, allowing for the brackish water system that exists today. As part of a South Florida flood control project, the South Fork of the estuary was connected to Lake Okeechobee to control lake water levels in 1924. Periodic high-volume flood control discharges from the lake have turned the entire estuary to fresh water from days to months at a time, causing considerable negative impacts to the system. Between 1935 and 1960, an extensive drainage system was constructed in the watershed, which included dredging and straightening the North Fork Narrrows, C-23, and C-24. Major effects of this drainage system include reductions in groundwater levels and evaporation as well as rapid watershed drainage manifested by changes in the quantity, quality, timing, and distribution of inflows to the estuary. Discharges from the lake, altered watershed hydrology, and water quality have degraded estuarine resources such as submerged aquatic vegetation, oyster communities, and fisheries.

The District's approach to address water management challenges for the SLE has grown more and more complex and comprehensive over the years. The first approach focused on the estuarine biological impacts of inflows from the watershed and Lake Okeechobee. Results of these studies offered a salinity or inflow envelope for estuarine biological resources, and a more environmentally friendly method of introducing low-level flood control discharges from the lake that emulates natural runoff hydrographs or pulses (Haunert and Startzman, 1980, 1985; SWIM, 2002). These results are presently used to manage lake elevations. The second approach incorporated and integrated the watershed hydrology with estuarine hydrodynamics and salinity. This allowed us to address the effects of altered watershed hydrology on estuarine biota and lead to the development of natural systems models to simulate natural surface water runoff characteristics to contrast with existing inflows. In order to emulate natural inflow distributions and characteristics, optimization models were used to determine the amount of storage or detention needed in the watershed, and, in general, how these facilities should to be operated. This method was used to create the CERP Indian River Lagoon – South Feasibility Report (U.S. Army Corps of Engineers, 2002) which describes the infrastructure proposed for the St. Lucie Estuary watershed to achieve natural inflows. Presently, the CED is focusing on the development of quantitative physicochemical and biological performance measures to gauge the health of the estuary. These performance measures will provide input/feedback to a new generation of optimization modeling designed to adaptively manage inflows on a daily basis considering conditions in the estuary. The implementation of CERP projects and the newly legislated St. Lucie Estuary Protection Plan will have great influence on the evolution of this project.

Watershed Data Collection and Modeling

The District's SLE watershed monitoring network consists of two elements (**Figure 4**). The Element 1 monitoring sites include the coastal structures from five major canals (C-23, C-24, C-25, C-44, and Gordy Road). The District has collected water quality samples at most of these structures since 1979. The drainage basins for the water quality monitoring (WQM) network include approximately 68 percent of the watershed. This portion of the watershed is predominately agricultural (70 percent) with 1 percent in urban land use. This long-term routine monitoring network collects grab samples monthly (nutrients, major ions, metals, and physical parameters), while auto samplers are used to collect weekly flow/time proportional composite samples (nutrients). In addition to water quality data, flows measurements are also conducted at these sites. These data are used to determine material loads to the receiving water body, identify long-term trends, calibrate and verify models, as well as evaluate the effectiveness of watershed BMP programs.

The Element 2 monitoring network covers the remaining 32 percent of the watershed. These tributary areas discharge surface water directly into the SLE (**Figure 4**). This portion of the watershed is 40 percent urban and 1 percent agricultural. The District has monitored water quality at these tributaries – the St. Lucie Tributaries (SLTs) – since November 2001. Originally, thirty-eight (38) sites were monitored biweekly for nutrients and physical parameters, with metals collected monthly. The SLT sampling network was reduced to nineteen representative sites in November 2003. As of January 2005, fourteen of the remaining nineteen sites have been instrumented with flow and rainfall measuring devices. Material loads associated with the urban service area will be quantified using this data associated with a watershed water quality model. The collected data are used to establish background or baseline datasets used to assist in characterizing sub-basin and tributary water quality behavior. These data will aid in determining source identification areas and model development.

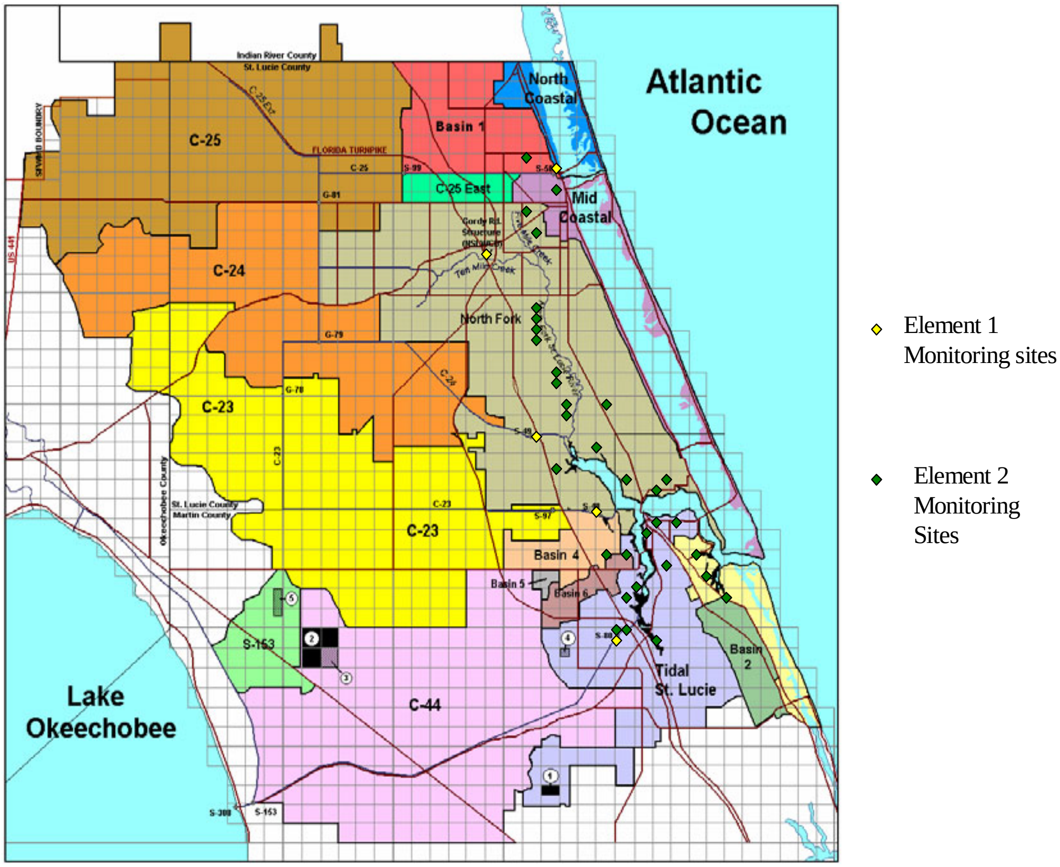


Figure 4. St. Lucie Estuary/Indian River Lagoon (SLE/IRL) basin boundaries and water quality monitoring locations.

Early work on the SLE watershed model efforts relied primarily on the modification and application of the HSPF. The project was completed in 1998 with the generation of the newest version of HSPF (Version 12). The model was implemented in the SLE/SIRL watershed and the modeling result was used in the Southern IRL Feasibility Study (Wan et. al., 2002).

In order to model watershed water quality and overcome the shortcomings of the aggregated nature of HSPF, the District initiated another project to develop a spatially distributed watershed hydrology and water quality model for the watershed (Wan et al., 2003). The model, named WaSh, is a time-dependent distributed watershed model representing detailed hydrology, hydrodynamics and nutrient water quality. The model is an integration of HSPF surface water hydrology, a MODFLOW-like groundwater model, a channel flow model, and newly developed components to represent the operation of flow control structures, reverse flows and groundwater-surface water exchanges. WaSh has been implemented in the SIRL watershed to simulate the complex natural systems, flat topography, high-water table conditions, operation of structures to control water levels and irrigation practices. The water quality component of the model is capable of simulating nutrient loading and detailed in-stream processes. The model is currently being used by the FDEP to develop TMDLs for the St. Lucie basins.

Estuarine Data Collection and Modeling

As part of the SWIM initiative, a long-term water quality monitoring program was started in October 1989 in the SLE (SWIM, 2002). Ten water quality monitoring stations were established to detect long-term spatial and temporal trends in the SLE (**Figure 5**). Data were collected biweekly from October 1990 through December 1996 and monthly from January 1997 to present. All samples were collected as close to low tide as possible. In situ physical parameters were taken using a Hydrolab Surveyor III multi-parameter sampling device. Physical parameters of temperature, pH, conductivity, and dissolved oxygen (DO) were sampled at half-meter increments from the bottom of the water column to the surface. Water samples were collected at half of the total depth for each sampling site. Samples were analyzed for turbidity (TURB), total suspended solids (TSS), color, total phosphorus (TP), total Kjeldahl nitrogen (TKN), orthophosphate (OPO_4), total nitrogen (TN), organic nitrogen (ORGN), nitrate + nitrite (NOX), and ammonia (NH_4). Chlorophyll *a* was collected at one-half of the Secchi disk depth. This data collection effort supports several critical restoration efforts in SLE, including SWIM and the restoration plan and implementation.

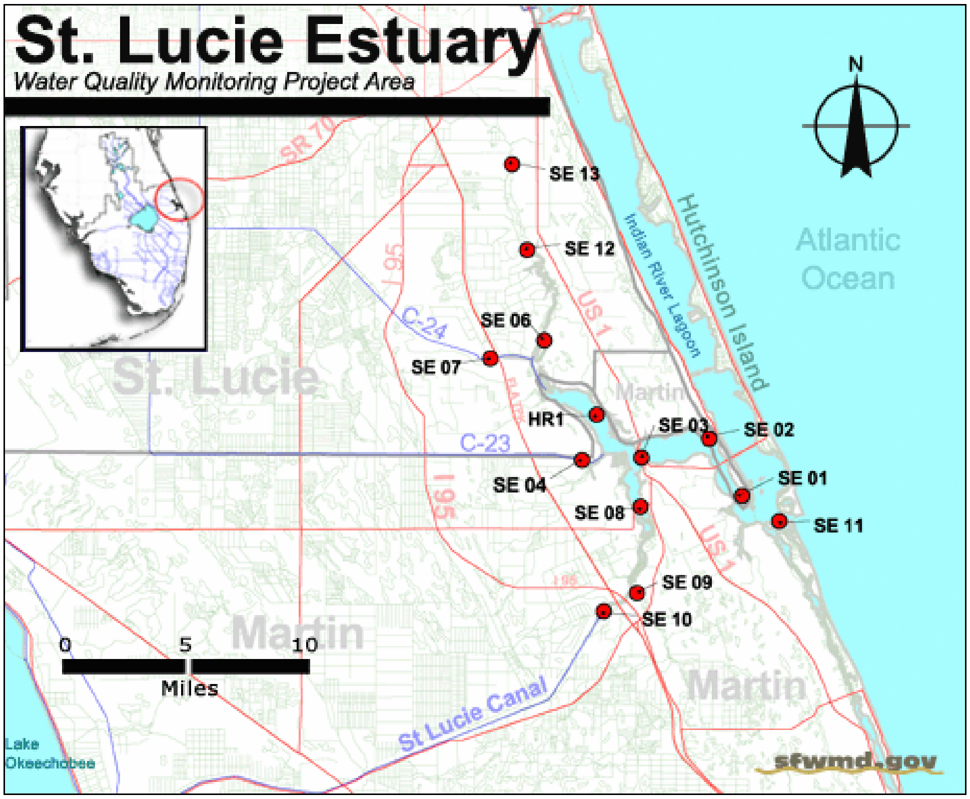


Figure 5. The St. Lucie Estuary (SLE) water quality monitoring network.

The pioneering modeling work in the SLE was the development of a one-dimensional hydrodynamic/salinity model, DYNTRAN (Morris, 1987) and then a two-dimensional hydrodynamic/salinity model using USACE computer models RMA-2 and RMA-4 (Hu, 1999). The outputs generated by these models have provided scientific support to the SIRL Restoration Feasibility Study and system operations. The RMA model was also adapted and extended to provide salinity prediction capabilities for establishing the SLE MFL.

Recently, the District developed a CH3D and Environmental Fluid Dynamics Computer Code (EFDC) hydrodynamic/salinity/water quality model (**Figure 6**) to evaluate the effectiveness of pollutant reduction strategies and the Ten Mile Creek facility. The CH3D is a three-dimensional, non-orthogonal curvilinear grid model which can provide reasonable boundary-fitting capability for complicated model areas. The model has been calibrated with three years (1999-2000 and 2003) data. The District is also in the process of modifying the EFDC water quality model into a stand-alone water quality model, so that it can be coupled with other hydrodynamic models such as CH3D. For approximately the past 10 years, the EFDC water quality model has been improved for the special needs of the District, including a SAV sub-model. The EFDC has also added macro-algae state variables to simulated attached algae on the bottom of a water body. The water quality model was calibrated for the years 1999 and 2000. A multiple-year simulation is being prepared and will be performed to study long-term water quality processes. The new simulation will take advantage of concurrent, continuous high-resolution in-situ measurements of water quality presently being measured such as Chl *a*, NH_4, soluble reactive phosphorus (SRP), DO, salinity, and turbidity at several locations to improve the model. One particular application of the modeling system is to assist the development of the strategy for stormwater management, such as the Ten Mile Creek Adaptive Management Program and flood control releases from Lake Okeechobee.

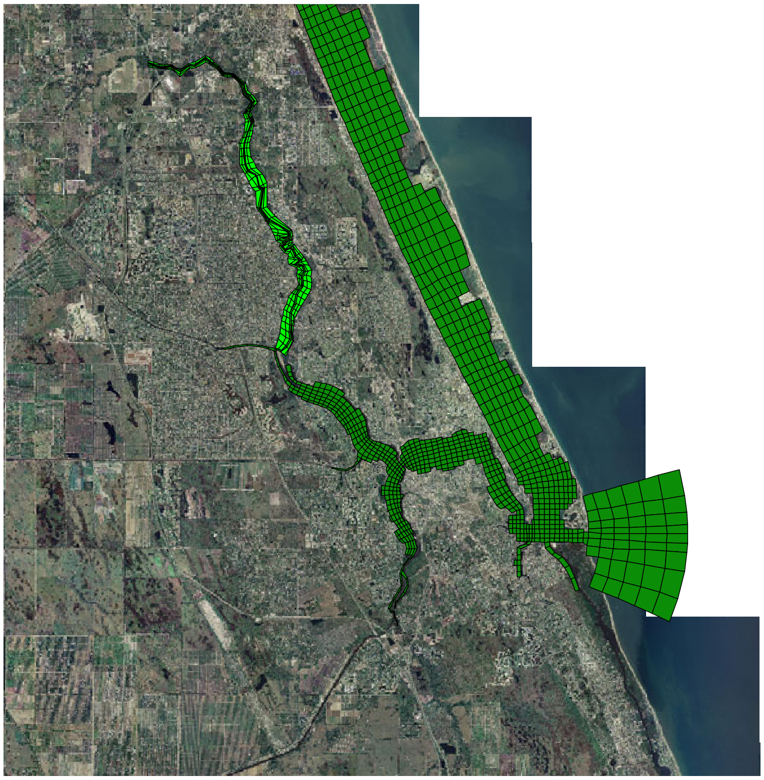


Figure 6. The SLE model domain.

Biological Investigations and VEC Evaluations

The District began biological investigations in the SLE in 1975 to document the effects of freshwater flood control discharges from Lake Okeechobee and the watershed on benthos and fishes (Haunert and Startzman, 1980, 1985). Benthos studies demonstrated that communities acclimated to mesohaline (5 to 18 ppt) salinities can be dramatically altered when discharges reduce salinities to oligohaline (0.5 to 5 ppt) conditions. Although these salinity zones are always moving in response to the watershed inflow, the addition of regulatory flood control discharges from the lake can severely increase the rate of change to and duration of oligohaline conditions in a large portion of the estuary. Sustained oligohaline conditions within a well-established mesohaline community, such as oyster reefs, can cause mass mortality and displacement of the community. Utilizing the abundant eastern oyster (*Crassostrea virginica*) found in the middle estuary as a Valued Ecosystem Component, the low-salinity physiological tolerance of the oyster and a one-dimensional estuarine salinity model (DYNTRAN) were utilized to form the recommendation that the mean monthly inflow from all sources of 2,000 cfs should not be exceeded more frequently than what would occur with natural watershed inflow conditions. The watershed model HSPF simulated the natural frequency distribution of runoff using 50 years of rainfall with natural watershed topographic relief. Both of the estuary and watershed models have been replaced by more sophisticated models (CH3D and WaSh, respectively) and are being used for developing water management alternatives to benefit VECs including the fisheries.

Fish captured with a seine and trawl during these early seasonal studies revealed resident estuarine fishes adapted to salinities throughout the estuary caused by watershed runoff. However, when lake flood control releases occur, the oligohaline area expands to accommodate greater quantities of freshwater species. Short-term responses of fish to three weeks of controlled releases of 1,000 cfs and 2,500 cfs from the lake into the South Fork of the estuary appeared to attract the larval stages of three primitive fishes (bonefish, tarpon, and ladyfish) and the common snook. However, the abundant lower trophic level fishes feeding on zooplankton (i.e., anchovies, sardines, and menhaden) increased in distribution throughout the estuary shortly after the controlled releases began, and then returned to their previous distribution, even though salinities were reduced. Nevertheless, overall analyses indicated that fish species composition remained similar throughout the five-week studies of controlled lake releases for three weeks. Overall, results from these fish studies indicated that capturing juvenile and adult fish with seine and trawl is not an appropriate method to determine the effects of inflows on fish life histories. Instead, since the early life histories of fish are most vulnerable to physicochemical changes, it was suggested that emphasis should focus on the relative success of estuarine-dependant fish spawning near the mouth of the estuary and the success of the associated year class within the low-salinity nursery areas.

Recent biological investigations (2005 to present) are emphasizing the relationship of inflows to the early life histories and movements of estuarine-dependent fish in the Southern Indian River Lagoon. It is known that many soniferous fish spawn repetitively at the same site over many annual cycles (Gilmore, 2002). It has been demonstrated within the Indian River Lagoon with spotted seatrout, *Cynoscion nebulosus*, (Gilmore, 2003) and, subsequently, in Pamlico Sound, North Carolina with silver perch, *Bairdiella chrysoura*, weakfish, *Cynoscion regalis*, (Luczkovich et al., 1999) and in Canada with Atlantic cod, *Gadus morhua* (Nordeide and Kjellsby, 1999) that spawning sound intensity correlated directly to the number of eggs in the water column, thus spawning success. Ambient salinity and temperature conditions dictate spawning activity due to egg/larval dependence of specific water environmental conditions (Alshuth and Gilmore, 1994). This means that if spawning success is to be accomplished, certain environmental conditions must be met. The agency can detect this activity through remote passive acoustic systems. Spawning intensity and locations of endemic soniferous fish (i.e., spotted sea trout, *C. nebulosus*, silver seatrout, *Cynoscion arenarius*, silver perch, *B. chrysoura*, Atlantic croaker, *Micropogonias undulates*, spot, *Leiostomus xanthurus*, red drum, *Sciaenops ocellata*, and several species of snook, *Centropomus* spp.) are being monitored acoustically in the outer estuary. Concurrent ichthyoplankton sampling is being conducted near the passive acoustic observatories to quantitatively relate the intensity of each species sonograph signature to the number of eggs spawned for each species. Once these relationships are established, costly net sampling in the outer estuary will be unnecessary to constantly monitor spawning success in relation to inflow conditions. Additional ichthyoplankton sampling throughout the estuary to determine density and distribution of fish eggs, larvae, and post larvae will, at a minimum, document the movement of fish larvae into the nursery areas, while concurrent sampling of zooplankton, phytoplankton (species abundance and limiting nutrients), water quality, turbidity maximum, and hydrodynamics will allow insight to the availability of larval fish foods and other phenomena during various inflow conditions. To monitor the movements of sub-adults and adult fishes of interest, acoustic tags are being surgically implanted that generate a unique sound for each fish. These broadcasts will be received by numerous hydrophones placed throughout the study area. It is anticipated that these studies will elucidate the temporal and spatial affects of freshwater inflows on the life histories of estuarine-dependant fish, leading to quantitative performance measures to guide water management decisions.

A major objective of the St. Lucie Estuary projects is to develop VEC evaluation tools. Once the cause and effect relationships of inflows on VECs are reasonably quantified, and used as performance measures of estuarine health, mathematical optimization techniques can be used to enhance water management operations in the watershed. Although past efforts have provided revealing insights into the relationship of inflows to estuarine VECs, a greater understanding of the eco-physiological requirements of several VECs are required for MFLs, Water Reservations, Lake Okeechobee regulation, and CERP/RECOVER. Examples of VECs appropriate for the St. Lucie Estuary include several species of submerged aquatic vegetation, oysters, early life history of estuarine-dependent fishes, and communities of wetland and floodplain vegetation in the tributaries. Thus far, modeling the effects of steady-state salinity on VECs has been the main focus; however, recently, the effects of water clarity, temperature, and salinity variation on the SAV tapegrass have been explored to make this SAV model more robust and useful for water management purposes. In order to advance understanding of the eco-physiological requirements of VECs, such as the early life history of estuarine fishes and oysters, information must be obtained from the literature, field observations, and mesocosm studies.

Planned Activities

Planned activities for St. Lucie Estuary are summarized in **Table 6**. Projects are focused on integration of the water quality model (CH3D/EFDC), watershed water quality model (WaSh), and fish life histories for use as a VEC. The integration of these provides a framework to accomplish the goal of establishing scientifically sound performance measures to enhance watershed infrastructure construction design and operations. Presently, the focus is on the development of quantitative physicochemical and biological performance measures to gauge the health of the estuary. Once the cause and effects of inflows on the biota can be reasonably quantified with certainty, mathematical optimization techniques can be utilized to water management.

In Fiscal Year (FY) 2008, the Coastal Ecosystems Division plans to:

1. Calibrate the CH3D water quality and sediment module and add the North Fork Narrows flood plain to the CH3D estuarine model.
2. Verify water quality module of the WaSh watershed model.
3. Determine if acoustic observatories in combination with plankton sampling can be used as a VEC and performance measure for fishes.
4. Expand fish nursery function sampling into the South Fork.

Future Information Needs

1. Mesocosm experiments on oysters, manatee grass, and fish larvae to quantify key physiological affects of water quality for VEC model development
2. Continued collection of water quality and biological data for model development

Table 6. Science program for St. Lucie Estuary. Area of SLE addressed: NFN = North Fork Narrows, NF = North Fork, SF = South Fork, ME = Middle Estuary (U.S. 1 to Hell's Gate), LE = Lower Estuary (North/South Intracoastal Waterway within several miles of St. Lucie Inlet). Sampling Frequency: S = Short term (one day or less), I = Intermediate term (every month or two months),

Study Title	Study Objective	Area of SLE Addressed	Sample Frequency	Timeline	Person of Contact
		Hydrology/Hydrodynamic/WQ Modeling			
Re-Rating Gordy Rd. Structure	Define new rating curve for structure	NFN		2007, 2008	*Yongshan Wan*
Acoustic Doppler's	Obtain vertical flow velocities for model	NFN, NF, ME, LE	S	2007	*Detong Sun*
Stage/Salinity Recorders Existing at NFN three bridges, HR1, Roosevelt and Evans Prairie Bridges	Obtain stage and salinity for model	NFN	S, I, L	2007 to ?	*Dan Crean*
Stage/Salinity Recorders (New) Palm City Bridge and SLE Inlet	Obtain stage and salinity for model	SF, NF, ME, LE	S, I, L	2007 to ?	*Dan Crean*
Bathymetry	Determine elevations for model	NFN		2007	*Dan Haunert*
Topography (LIDAR): North Fork Narrows Floodplain and TMC STA	Obtain elevations for modeling	NFN		2007	*Cecilia Conrad*
Floodplain Model for CH3D	Enhance CH3D to include floodplain	NFN		2007-2009	*Gordon Hu, Detong Sun*
Nutrient Benthic Flux	Determine nutrient dynamics for model	NFN, NF, SF ME, LE		2008,2010	*Detong Sun*
Optimization of Operations Ten Mile Creek Facility	Provide environmental sensitive operations for the TMC facility	NFN, NF, SF ME, LE		2007-2011	*Yongshan Wan*
Tributary WQ Loading	Obtain nutrient loading for model	NFN, NF, SF	S, I, L	2007 to ?	*Boyd Gunsalus*
In-Situ Water Quality in NFN / Hell's Gate (Micro labs)	Obtain high resolution water quality data for model	NFN, ME	S ,I, L	2007-2009	*Dan Crean*
SLE/IRL SFWMD WQ Sampling	Obtain long term WQ data for model and historical database	NFN, NF, SF ME, LE	I	2007 to ?	*Dan Crean*
Flow Through WQ, North Fork Narrows	Evaluate inflow and turbidity maximum	NFN	S	2007-2009	*Dan Haunert*
Ten Mile Creek Facilities Water Quality Modeling	Optimize operations for nutrient assimilation			2008-2011	*Detong Sun*
		VEC Assessments			
Wetland and Floodplain Habitat Mapping	Define habitat/elevation relationship for CH3D model	NFN	L	2007,2008	*Marion Hedgepeth*
SLE Tape Grass Modeling	Determine if tape grass can inhabit North Fork	NFN, NF	L	2008	*Melody Hunt, Dan Haunert*
IRL Seagrass Monitoring	Determine relationship of water quality and seagrass presence	LE		2007 to ?	*Becky Robbins*
Phytoplankton and Nutrient Loading	Determine limiting nutrients for model and TMDL	NFN, NF, SF ME, LE	I	2007-2009	*Dan Haunert*
Zooplankton: Fish Nursery Prey	Determine relationship among inflow, ichthyoplankton and prey density for VEC model	NFN, NF	S, I	2007-2009	*Dan Haunert*

Table 6. Continued.

Study Title	Study Objective	Area of SLE Addressed	Sample Frequency	Timeline	Person of Contact
VEC Assessments					
Benthic Macro-invertebrate Community Surveys	Classify habitat quality	NFN, NF, SF ME, LE	L	2007-2009	*Tunberg (Smithsonian)*
Oyster health, density and mapping	Determine oyster health and distribution plus develop VEC model	NF, SF, ME	I	2007 to ?	*Bill Arnold (FFWCC)*
Ichthyoplankton Surveys	Determine relationship among inflow, ichthyoplankton and prey density for VEC model	NFN	I	2007-2009	*Dan Haunert*
Croaker, Silver perch, Snook Acoustic Tagging	Determine life history of estuarine dependent fish for VEC model	NFN, NF, SF ME, LE	S, I, L	2007-2009	*Dan Haunert*
Acoustics: Fish Spawning	Document fish spawning and intensity for VEC model	NFN, ME, LE	S, I, L	2007 to?	*Dan Haunert*

SOUTHERN INDIAN RIVER LAGOON SCIENCE INVENTORY

The Indian River Lagoon extends approximately 250 kilometers along the east coast of Florida from the Ponce de Leon Inlet in Volusia County to the Jupiter Inlet in Palm Beach County. Because the lagoon falls within both water management districts, the South Florida Water Management District (SFWMD) and St. Johns River Water Management District (SJRWMD) work cooperatively on lagoon water management issues. The southern 75 kilometers of the lagoon, between the Indian River/St. Lucie County line and the Jupiter Inlet (see **Figure 7**) comprises the portion of the lagoon within the boundaries of the SFWMD. The SIRL is flushed by three inlets: Ft. Pierce, St. Lucie, and Jupiter. Major freshwater sources to the SIRL include the C-25 canal (Taylor Creek), Basin 1, and the St. Lucie River.

Data collection began in the late 1980s in support of the Indian River Lagoon (IRL) Surface Water Improvement and Management (SWIM) Plan. Data collection, focusing primarily on SAV and water quality, continues in support of (1) the IRL Surface Water Improvement and Management Plan, (2) the National Estuary Program's Indian River Lagoon Comprehensive Conservation and Management Plan (NEPCCMP), (3) Comprehensive Everglades Restoration Plan's (CERP's) Monitoring and Assessment Plan (MAP), and (4) the District's Lake Okeechobee operations.

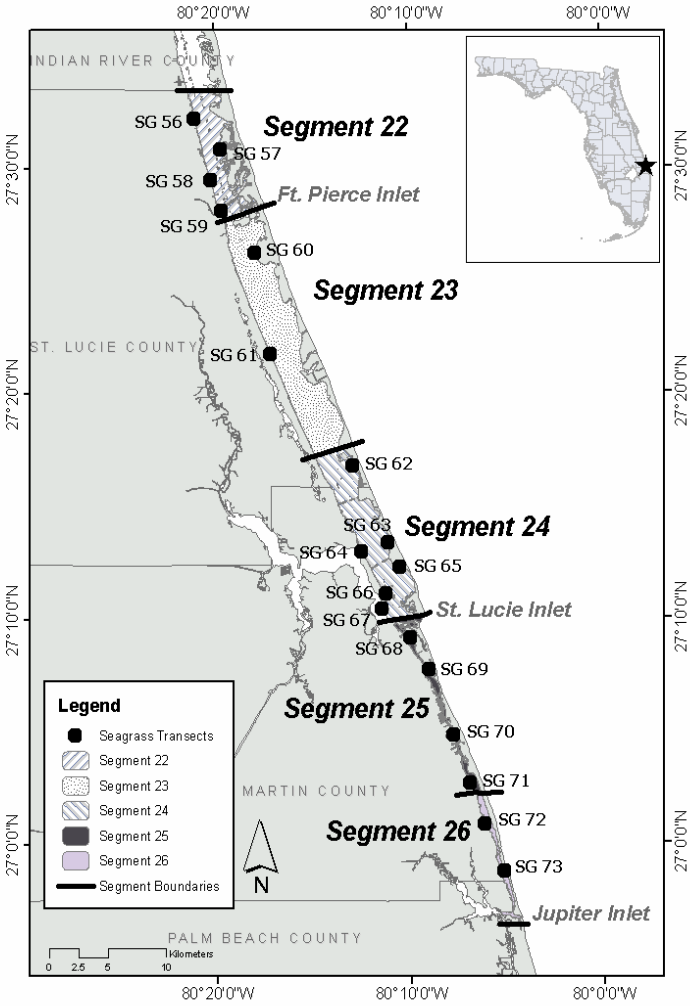


Figure 7. Location map of the Southern Indian River Lagoon showing inlets, major tributaries, management segments, and seagrass transects (SG#).

Submerged Aquatic Vegetation has been identified as the SIRL VEC through SWIM, NEPCCMP, and CERP programs. The St. Johns and South Florida Water Management Districts have identified 26 seagrass management units or "segments" throughout the IRL (Steward et al., 2003). Five of these segments, Segments 22 through 26, lie within the SIRL (see **Figure 7**). The segment boundaries primarily follow the boundaries of five relatively homogeneous water quality zones. Other factors, such as physical configuration and surrounding land use, also support the segmentation scheme.

The St. Lucie River is the largest tributary to the SIRL. Discharges from the river to the lagoon include watershed runoff and regulatory releases from Lake Okeechobee. Elevated freshwater discharges into the SIRL from the river can result in increased color and turbidity (hence increased light attenuation) and lowered salinities, which inhibit seagrass growth (Crean et al., 2007). SAV species present in the SIRL, such as *S. filiforme,* are harmed by excessively low salinities and highly variable salinity regimes (Irlandi, 2006) that can occur during large discharges.

Managing the frequency and duration of freshwater discharges in relation to the species-specific physiological requirements of seagrasses should result in appropriate salinity regimes and increased light penetration through a reduction in turbidity and color. The construction and operation of water storage and treatment facilities in the St. Lucie Watershed, as part of the CERP, are expected to provide salinity envelopes that avoid ecologically damaging high-salinity extremes and associated water quality degradation in the SIRL.

Submerged Aquatic Vegetation Mapping and Monitoring

Understanding the dynamics of SIRL SAV is being addressed through mapping by acquisition of aerial photographs that are photo-interpreted, ground-truthed, and used to develop SAV maps. The goal of these efforts is to identify areas of change (loss or gain) and those that are stable over time to gain a better understanding of dynamics at an estuarine and segment scale. The SFWMD and SJRWMD work cooperatively to produce these maps every two to three years, with aerial photos flown annually to fill in any information gaps between mapping years. An example of a map produced through this mapping process is shown in **Figure 8**. The District has also obtained historic SAV datasets (based on interpretation of best available aerial photographs, but without ground truthing) for the following time periods: the 1940s, 1950s, 1970s, and early 1980s.

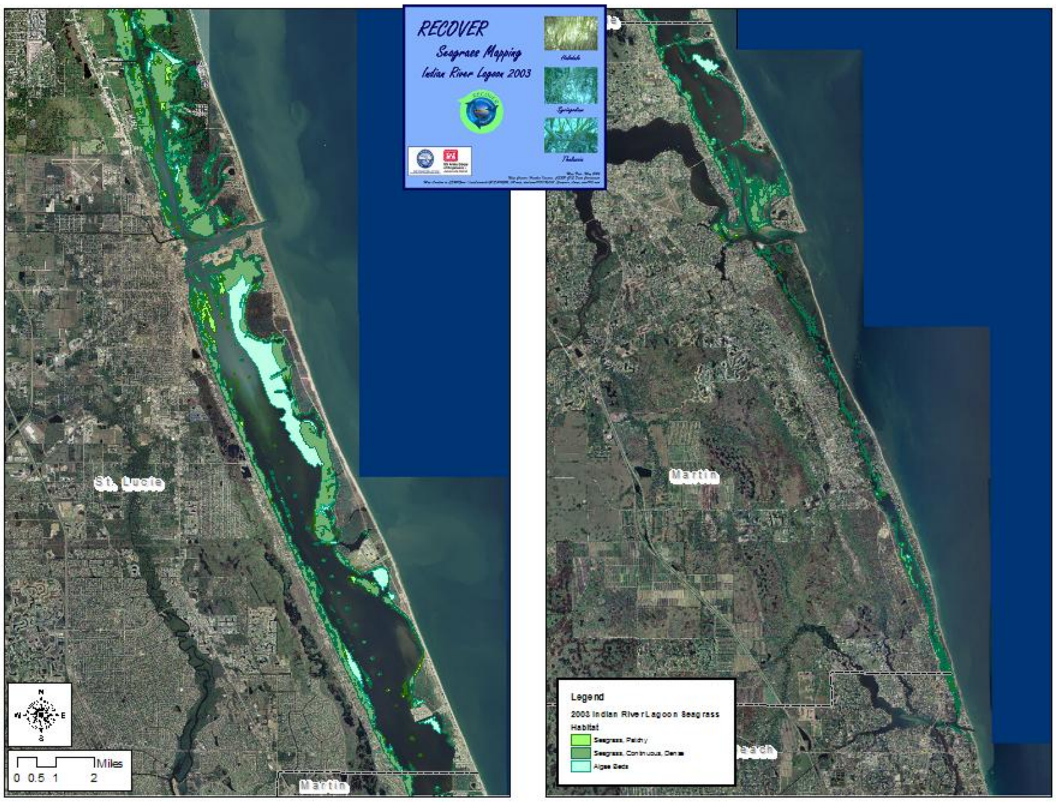


Figure 8. An example of a submerged aquatic vegetation map created from interpreting 2003 aerial photographs of the Southern Indian River Lagoon (SIRL).

One limitation of maps created from aerial photographs is that they are not species-specific. Six seagrass species are known to occur in the SIRL: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), paddle grass (*Halophila decipiens*), Johnson's seagrass (*Halophila johnsonii*), and star grass (*Halophila engelmanni*). Understanding seagrass species distribution is important for water management practices because the seagrass species found in the SIRL have species-specific salinity thresholds (Irlandi, 2006). To help understand species distributions, a test area near the mouth of the St. Lucie River is scheduled to be mapped to the SAV species level during the summer of 2007 using aerial photographs as a guide, but relying primarily on ground-truthing, using sub-meter accuracy GPS technology.

In addition to mapping data, the SFWMD in cooperation with the SJRWMD and other agencies, conducts monitoring twice a year throughout the entire lagoon. Sites monitored within the SIRL are shown in **Figure 9**. Many of these sites have been monitored since the summer of 1994. Seagrass transect monitoring is conducted at fixed locations marked with permanent stakes. Each transect extends from the shore to the deep edge of the seagrass bed. One meter square quadrats are placed at regular intervals along the transect line. Seagrass measurements taken within the quadrats include density, percent cover, percent occurrence, canopy height, and shoot counts.

Additional in-situ monitoring in the SIRL was initiated in 2002 to better understand (1) the natural seasonal variability of seagrass, and (2) the response of the seagrass community to freshwater discharge. This study was designed to document changes in seagrass percent cover, shoot counts, percent occurrence, species composition, canopy height, and reproductive status at monthly intervals at sites influenced by St. Lucie River discharges (**Figure 9**). Monitoring for this project is expected to continue through August 2007 to provide a five-year dataset. Monthly seagrass status reports are provided to the SFWMD Lake Okeechobee operations decision-making team as one of their tools for evaluating appropriate lake management.

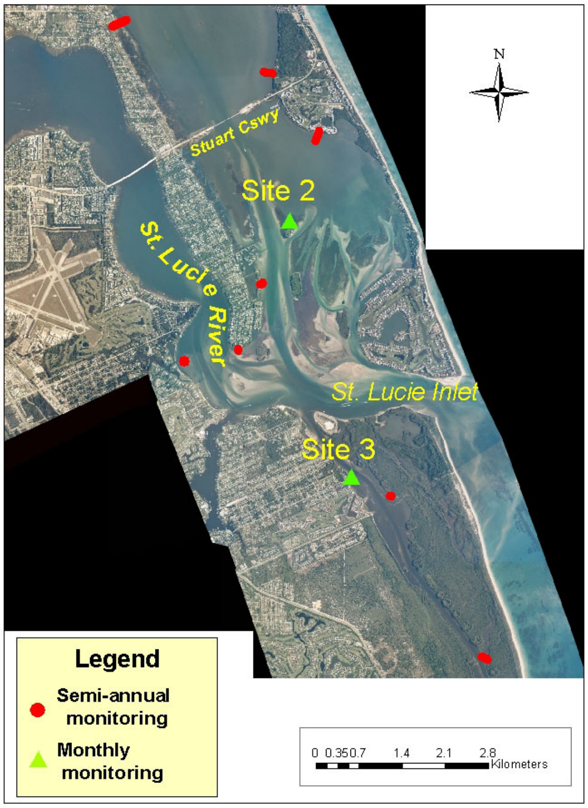

SEAGRASS MONITORING LOCATIONS

Figure 9. Location of seagrass monitoring sites near the mouth of the St. Lucie River.

Water Quality Monitoring

Forty SIRL water quality stations were monitored quarterly (January, April, July, and October) by the District from October 1990 to July 1999. This monitoring program was established to detect long-term water quality trends in the SIRL. Physical measurements collected at each monitoring station consisted of temperature, dissolved oxygen, pH, conductivity, salinity, and Secchi disk depth. Water samples were collected for the following parameters: total Kjeldahl nitrogen, total phosphorus, nitrite + nitrate, orthophosphate, total suspended solids, volatile suspended solids, turbidity, chlorophyll *a*, and color. Additionally, photosynthetically active radiation (PAR) was measured.

To better understand the water quality/seagrass link in the SIRL, modifications were made to the SIRL water quality monitoring network. Beginning January 10, 2000, water quality stations were co-located with 10 of the 18 seagrass transects in the SIRL (**Figure 10**). The monitoring was increased from quarterly to seven times a year.

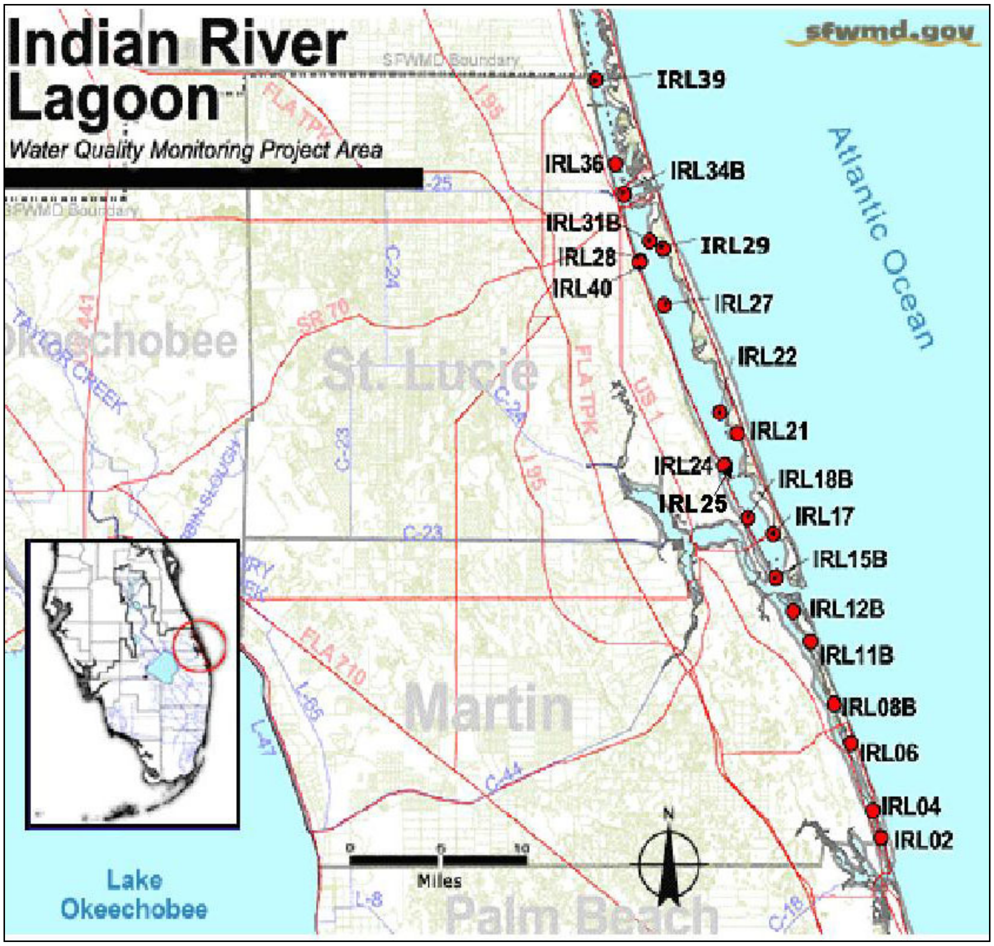


Figure 10. Water quality monitoring stations in the SIRL.

Watershed and Estuary Modeling

Watershed modeling using WaSh is completed for the C-25 basin and Basin 1, and for the St. Lucie Estuary Watershed. Freshwater inflow and nutrient loading simulations are available as input data for three-dimensional simulation of salinity and water quality in the lagoon using CH3D (**Figure 11**). These models are calibrated using data collected in the lagoon and its watershed. The modeling results provide detailed temporal and spatial salinity and water quality data for seagrass evaluation and future development of a seagrass model in the lagoon.

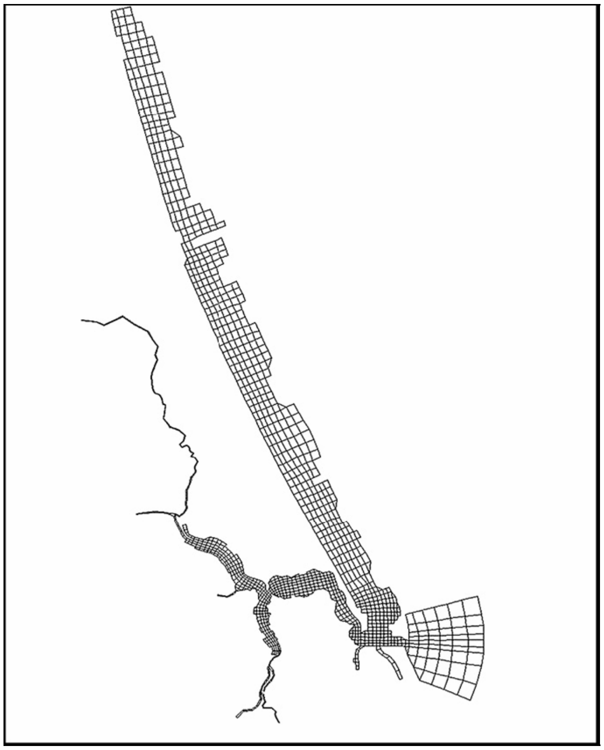


Figure 11. Model grids of the three-dimensional model of the SLE and SIRL.

Valued Ecosystem Component Analysis

Seagrass mapping and transect data and associated water quality data are summarized in the 2002 IRL SWIM Plan Update (Steward et al., 2003). A change analysis of seagrass mapping data from 1986 through 1999 was provided by Robbins and Conrad (2001). This report included an evaluation of the IRL SWIM depth target of 1.7 m to determine the percentage of "potential habitat" covered by seagrass per year. Depth data used in this evaluation was based on the 1997/1998 SIRL bathymetric survey data. Water quality and seagrass data collected from 1990 to 1999 for the SIRL were evaluated to establish a correlative link between water quality and the performance of seagrass, and to use water quality at the best-performing seagrass sites to establish water quality targets for protecting and restoring seagrass (Crean et al., 2007). Additional data analysis is provided in various RECOVER MAP reports and monthly updates to support Lake Okeechobee operations decision making.

Planned Activities

Some recent investigations are summarized in **Table 7**. In FY2008 and FY2009, the Coastal Ecosystems Division plans to do the following:

Data Collection

3. Work cooperatively with the SJRWMD to acquire aerial photography of the entire lagoon.
4. Conduct semi-annual SIRL seagrass monitoring.
5. Revise the monthly SAV monitoring program to match the RECOVER unified monitoring approach. Continue to provide updates for support of Lake Okeechobee operations decision making.

6. Contract out a bathymetric survey of the SIRL to update the data collected in 1997/1998.
7. Continue to provide oversight of the SIRL Water Quality Monitoring Network.

Data Evaluation

1. Data evaluation/reporting for SAV monthly, semi-annual, and mapping data. Complete change analysis through 2007, evaluate SAV targets by segments (and perhaps sub-segment).
2. Evaluate and summarize hurricane impacts from GIS and field data, define "natural variability" from available GIS data and field data, and evaluate relationships between SAV parameters and water quality (including modeled salinity).

One SAV issue unique to some the estuaries, including the SIRL, is the presence of *Halophila johnsonii*. Johnson's seagrass is the only seagrass species listed as "threatened" by the federal government. It is listed as threatened because of its limited geographic distribution; it has only been found along the Florida east coast, from Sebastian Inlet to northern Biscayne Bay. Little is known about the salinity thresholds of this federally threatened seagrass species. Studies are needed to help evaluate Johnson's seagrass thresholds.

Integrated Modeling and VEC Assessment

1. Reevaluation of SIRL seagrass water quality targets based on data available since 1999 and three-dimensional salinity and water quality simulations
2. SAV model development

Table 7. Recent investigations in the SIRL.

Water Body	SIRLStudy Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Plan Milestone
			Hydrodynamic Modeling			
Southern Indian River Lagoon	Bathymetric Survey – 1997/1998	Gordon Hu	1997-1998	District GIS	Data for modeling and SAV depth target analysis	Freshwater inflow studies
Southern Indian River Lagoon	Bathymetric Survey – 2008	Cecilia Conrad	2008	District GIS	Update system bathymetry for modeling and SAV depth target analysis	Freshwater inflow studies
			SAV Assessment			
Southern Indian River Lagoon	Aerial photography	Becky Robbins	Annual	District	Documentation of SAV coverage	Freshwater inflow studies
Southern Indian River Lagoon	SAV Mapping	Becky Robbins	1986 – ongoing (every 2-3 years)	District	Documentation of SAV coverage and variability of coverage	Freshwater inflow studies
Southern Indian River Lagoon	In situ SAV monitoring	Becky Robbins	1994 – ongoing	District	Species specific data for evaluating background conditions, changes over time, and linkage with water quality	Freshwater inflow studies
Southern Indian River Lagoon	SAV salinity literature review	Becky Robbins	2006	District	SAV species specific salinity thresholds (current literature review)	Freshwater inflow studies
			Water Quality			
Southern Indian River Lagoon	WQM	Dan Crean	1990 – ongoing	District	Water quality trends and relationship to SAV	Freshwater inflow studies
Southern Indian River Lagoon						
			Fish Studies			
Southern Indian River Lagoon	Seine sampling	Dan Haunert	2006 – ongoing	District	Linkage of fish and SAV	Freshwater inflow studies
			Benthic Studies			
Southern Indian River Lagoon	Bethic infauna monitoring	Barb Welch	2005 – ongoing	District	Linkage of benthos and SAV	Freshwater inflow studies

LOXAHATCHEE RIVER AND ESTUARY SCIENCE INVENTORY

The Restoration Plan for the Northwest Fork of the Loxahatchee River identifies the problems experienced by the ecological system, which are caused by tidally influenced saltwater intrusion and dry season flow deficiencies due to man-made activities. A Preferred Restoration Flow scenario was developed using the integrated modeling and assessment framework (see main body of Science Plan, (**Figure 3**) and employed best available data and watershed and estuarine models. The models identify supplemental, variable flows, daily and seasonally, that are necessary for improvements to occur within the ecological system between River Mile (RM) 6 and River Mile 15.5 of the Northwest Fork (see **Figure 12**).

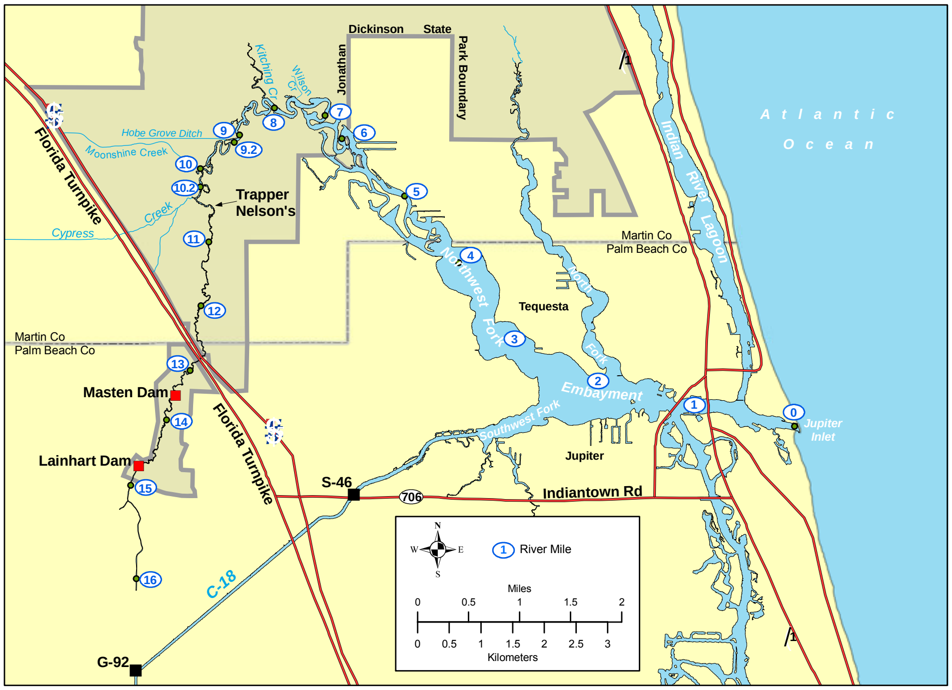


Figure 12. Loxahatchee River showing river miles.

The Northwest Fork Ecosystem was characterized by five Valued Ecosystem Components (VECs):

1. Cypress swamp and hydric hammocks in the freshwater riverine floodplain from RM 16 to RM 9.5.
2. Cypress swamp in the tidal floodplain from RM 9.5 to RM 5.5
3. Fish larvae in the low-salinity zone from RM 9.5 to RM 5.5
4. Oysters in the mesohaline zone from RM 6 to RM 4
5. Seagrasses in the polyhaline zone downstream from RM 4 to RM 0.

The analysis provides close approximations of optimal wet and dry season hydroperiods for the cypress swamp in the freshwater floodplain. In addition, dry season variable, restorative flows will push the saltwater front downstream to allow recruitment of freshwater species in the upper tidal floodplain, while minimizing impact on the estuarine systems. There will be some impact on oyster beds at River Mile 6, and minimal impact on seagrasses in the Central Embayment area at River Mile 2. The Preferred Restoration Flow Scenario is expected to protect the freshwater floodplain and reverse saltwater intrusion that will restore portions of the tidal floodplain to freshwater swamp.

During the development of the Restoration Plan, existing data collection and monitoring programs were evaluated to identify those that were essential for assessment of restorative flows. It was equally important to obtain new information where there were data gaps or insufficiencies. The Science Inventory for the Northwest Fork of the Loxahatchee River is designed to provide adequate information (best available data) so that flows to the Northwest Fork are based on adaptive management for the achievement of a healthy ecosystem.

The Restoration Plan for the Northwest Fork of the Loxahatchee River is the basis for the management of flows to protect and restore the freshwater floodplain, tidal floodplain, and estuarine reaches. Monitoring programs identified in the science plan for the Northwest Fork of the Loxahatchee River should provide the data and information necessary to:

1. Characterize the condition of each of the river reaches, especially the VECs in terms of
    a. The duration and timing of flows and associated water stages
    b. Water quality such as salinity and other constituents
    c. Select flora
    d. Select fauna
2. Observe changes in monitored constituents on an ongoing basis
3. Measure and quantify changes and trends in the monitored constituents during restoration activities
4. Support ongoing and future modeling activities

In summary, the science plan for the Northwest Fork of the Loxahatchee River is designed to establish and support monitoring programs which gather information on a structured, focused basis that provide information on water quantity, water quality, timing, and distribution of increased dry season flows and improved wet season flows. The information will be used for modeling, predictive analysis, and evaluation purposes, which will form the basis for adaptive management decision making for operational protocols, regulations such as the Regional Resource Availability Rule and water reservations and CERP project components and other regional projects. **Table 8**, which follows, summarizes the science plan.

Table 8. Draft Northwest Fork of the Loxahatchee Science Plan Projects.

Project Title	New or Existing	Lead Agencies	Priority	Valued Ecosystem Component (VEC) or Ecological Section or River Reach being Addressed	Project Objective	Project Term	Project Committee Members (bolded denotes committee leader)
A. Hydrology/Hydraulics							**Wan**, Hu, Hansen
A, B, C. Soil Salinity and Moisture Monitoring	New	SFWMD	1	FWF, TF	Physical/ chemical baseline; Modeling	L, I, S	**Hedgepeth,** Gunsalus, Roberts, Rossmanith
A. Existing Groundwater Monitoring Network	Existing	SFWMD	1	FWF, TF	Physical/ chemical baseline; Modeling	L, I, S	**Hu** Hedgepeth, Roberts, Rossmanith
A. Short-term Intensive Groundwater Monitoring (HOBOs)	New	SFWMD	2	FWF, TF	Physical/ chemical baseline; Modeling	S	Gunsalus, Hedgepeth, Roberts, Rossmanith
A. Rainfall Monitoring Network	Existing	SFWMD	1	All	Physical/chemical baseline; Modeling	L, I, S	TBD
A. Existing Stage/Flow Monitoring Network	Existing	SFWMD	1	All	Physical/chemical baseline; Modeling	L, I, S	**Hu**
A. Additional Stage/Flow Monitoring Needed	New	SFWMD	2	All	Physical/chemical baseline; Modeling	L, I, S	**Hu**
A. Tide/Salinity Monitoring Network	Existing	USGS	1	TF,O, M, P	Physical/chemical baseline; Modeling	L, I, S	**Hu**
A. Tidal Boundary Estuarine Model	New	SFWMD	1	All	Modeling		**Hu**
A. Digital Elevation Model, a GIS based inventory model i.e. topography, essential habitats, vegetation, etc.	New	SFWMD	1	All	Physical/chemical baseline; Modeling; Evaluation	L, I, S	**Conrad**
A. Operational Criterion for G-92, Optimization Model	New	SFWMD	1	All	Modeling	L, I, S	**Wan**, Arrington, Roberts, Haunert
A. Integrated Model Development	Existing	SFWMD	1	All	Modeling	L, I, S	**Hu**
B. Water Quality							Arrington, Gunsalus

Table 8. Continued.

Project Title	New or Existing	Lead Agencies	Priority	Valued Ecosystem Component (VEC) or Ecological Section or River Reach being Addressed	Project Objective	Project Term	Project Committee Members (bolded denotes committee leader)
B. LRD Data Sonde Project	Existing	LRD	3	All	Physical/chemical baseline; Modeling	L, I, S	Hu
B. Enhancement of LRD Riverkeeper WQ Monitoring	New	LRD	1		Physical/chemical baseline; Modeling	L, I	Arrington, Maxted, Hedgepeth
B. Water Quality Event Loading	New	LRD, FDEP	2	All	Physical/chemical baseline; Modeling	L, I, S	Hu
B. Estuarine Water Quality Model (See Integrated Model A)	Existing	SFWMD	1	TF, O, M, P	Physical/chemical baseline; Modeling	I, S	Hu
C. Wetland and Floodplain Habitat							Hedgepeth, Gunsalus, Roberts
C. Seedling Production Study	Existing	SFWMD	2	FWF, TF	Biological Response	S	Hedgepeth
C. JDSP Vegetation Demo Project	Existing	FPS	3	All	Evaluation	L	Rossmanith
C. Vegetation Response to Severe Weather Events	Existing	FPS	3	FWF, TF	Biological Response	S	Rossmanith
C. Vegetation Canopy Transect Monitoring	Existing	FPS	1	FWF, TF	Biological Response	L	Rossmanith, Roberts
C. Vegetation Transects Photo Points	New	FPS	1	FWF, TF	Biological Response	L	Rossmanith, Roberts, Hedgepeth
C. Ground Cover Monitoring	Existing	FPS	1	FWF, TF	Biological Response	L	Hedgepeth, Roberts
C. Juvenile Plant Growth	Existing	FPS	3		Biological Response		Hedgepeth, Roberts
C. Primary Production	New	?????	2	FWF, TF	Biological Response		Maxted, Arrington
D. Shoreline Habitat							
Addressed in DEM							

Table 8. Continued.

Project Title	New or Existing	Lead Agencies	Priority	Valued Ecosystem Component (VEC) or Ecological Section or River Reach being Addressed	Project Objective	Project Term	Project Committee Members (bolded denotes committee leader)
E. Birds							Cowan, Roberts
E. Bird Monitoring	New	FPS	1	FWF, TF	Biological Response	L, I	**Cowan, Merritt**
F. Mammals							**Rossmanith**
F. Small Mammal Monitoring	New	FPS	1	FWF, TF	Biological Response	L, I	Rossmanith
G. Reptiles and Amphibians							Rossmanith, Roberts
G. Amphibian Populations' Response to Flows	New	FPS	1	FWF, TF	Biological Response	L, I	**Rossmanith**
H. Phytoplankton & Zooplankton							Haunert
H. Primary Production and Nutrient Loading	New	SFWMD	2	O, M, P	Biological Response	I, S	**Haunert**
I. Oysters							Haunert, Arrington
I. Oyster Monitoring/Mapping	New	SFWMD, LRD	1	M	Biological Response	L, I	**Arrington**
I. Oyster Restoration	New	LRD	3	M	Evaluation	L	**Arrington**
J. Other Benthic Communities							Arrington, Maxted,
J. Estuarine Macroinvertebrates Monitoring	New	?	4	O	Biological Response	L, I	**Haunert**
J. Freshwater Macroinvertebrates Monitoring	New	SFWMD, LRD	1	FWF	Biological Response	L, I	**Maxted** **Arrington**
J. Tidal VEC determination/monitoring	New	SFWMD, LRD	1	P	Biological Response		**Haunert**, Arrington

Table 8. Continued.

Project Title	New or Existing	Lead Agencies	Priority	Valued Ecosystem Component (VEC) or Ecological Section or River Reach being Addressed	Project Objective	Project Term	Project Committee Members (bolded denotes committee leader)
K. Fish Communities							Haunert, Arrington, Roberts
K, D Estuarine/Saltwater Fishes	New	SFWMD	2	TF, O, M, P	Biological Response	L, I, S	Haunert Arrington
K. Seagrass Fishes	New	LRD	2		Biological Response		Arrington
K, D Freshwater fishes floodplain, NWF and Tributaries	New	FPS	1	FWF, TF	Biological Response	L, I, S	Hedgepeth, Roberts
K, D Freshwater fishes Channel, NWF and Tributaries	New	FPS	1	FWF, TF	Biological Response		Hedgepeth, Roberts
K, H, D. Fish Larvae and Juveniles Response to Flow, Turbidity Maximum	New	SFWMD	1	TF, O, M	Biological Response	I, S	Haunert
K, M. Grey Snapper Population Dynamics	New	LRD	4	TF, O, M, P, Offshore	Biological Response	L, I, S	Arrington
K, M. Loxahatchee Snook Life History	New	SFWMD, LRD	3	TF, O, M, P	Biological Response	I, S	Haunert
L. Submerged Aquatic Vegetation SAV							Arrington, Robbins
L, K, J, Mesocosm Studies	New	SFWMD	2	All	Modeling		Haunert, Robbins
L. Seagrass and Macro-algae Monitoring (Monthly)	Existing	LRD	1	M, P	Biological Response	L, I, S	Arrington, Robbins
L. Seagrass species-specific Mapping	Existing	LRD	1	M, P	Biological Response	L	Arrington, Robbins

Table 8. Continued.

Project Title	New or Existing	Lead Agencies	Priority	Valued Ecosystem Component (VEC) or Ecological Section or River Reach being Addressed	Project Objective	Project Term	Project Committee Members (bolded denotes committee leader)
M. Ecosystem Dynamics							Arrington, Roberts
M. Carbon flow & food web dynamics	New	LRD	3	All	Evaluation	I, S	Arrington,
N. Database Management							
N. Program Data Management	New	SFWMD	1	All	Evaluation	L, I, S	Marley, Heather
O. Modeling							
O. Analysis for the Modification of Existing Models and Development of New Models	New	SFWMD	1	All	Modeling		Wan

LEGEND:

- “Priority”: 1 is the highest rating.
- LRD: Loxahatchee River District
- NWF: Northwest Fork
- “Ecological Section” is the area the project addresses: FWF = Freshwater Floodplain, TF = Tidal Floodplain, O = Oligohaline, M = Mesohaline, and P = Polyhaline.
- “Term of Project” is the length of time the project will take.
- “C” means the project is continuous.
- “Years” is the frequency of project implementation (i.e., 1 to 5 is every year in five-year plan).

LAKE WORTH LAGOON SCIENCE INVENTORY

The Lake Worth Lagoon extends for approximately 22 miles in central Palm Beach County, Florida (see **Figure 13**). The lagoon is typically 6 to 10 feet in depth. The Atlantic Intracoastal Waterway channel runs the entire length of the lagoon.

The Lake Worth Lagoon watershed is highly urbanized and encompasses over 450 square miles that ultimately drain to the North Lake Worth (Palm Beach) Inlet and South Lake Worth (Boynton) Inlet. This watershed includes the communities of North Palm Beach, Lake Park, Riviera Beach, Magnolia Park, Palm Beach Shores, West Palm Beach, Palm Beach, South Palm Beach, Lake Worth, Lantana, Hypoluxo, Manalapan, Boynton Beach, and Ocean Ridge.

Sources of water include the Atlantic Ocean via two permanent inlets, watershed runoff from primary and secondary canal systems, and precipitation. The major sources of fresh water are the C-17 canal (Earman River), C-51 canal (West Palm Beach Canal), and the C-16 canal (Boynton Canal). The C-51 canal contributes approximately 50 percent of the fresh water that reaches the lagoon, with 75 percent of the flow northward and 25 percent southward (Chui et al., 1970).

Figure 13. Location of Lake Worth Lagoon.

Similar to many of South Florida's heavily urbanized coastal areas, Lake Worth Lagoon has been negatively impacted by anthropogenic changes. Currently, the Lagoon receives too much runoff in the wet season and fewer freshwater discharges during the dry season, and it is subjected to extreme salinity fluctuations and high levels of turbidity and sedimentation.

Approximately 81 percent of the shoreline is hardened with only a small percent of the shoreline fringed by mangroves. Various monitoring and modeling activities have been ongoing for the last several decades in the lagoon and the watershed. Since 1994, there has been a heightened awareness of the need for water quality improvements and habitat restoration and enhancement within the Lake Worth Lagoon. A Lake Worth Lagoon Management Plan was approved in 1998 to guide monitoring, restoration, and enhancement. These efforts have been highly dependent on multiagency cooperative efforts in coordination with Palm Beach County Department of Environmental Resources Management (PBC-ERM) and the FDEP.

Specific assessment criteria for Lake Worth Lagoon relate to the effects of hydrology on (1) freshwater flows and salinity regimes, (2) water quality, and (3) biological resources; i.e., seagrasses and oysters. Further information is available at http://www.pbcgov.com/erm/enhancement/Images/PDF_Documents/LWL_Report.pdf.

The Lake Worth Lagoon has been divided into three segments (north, central, and south) based on hydrological factors including water quality, circulation, and physical characteristics (see **Figure 14**).

Lake Worth Lagoon North

Lake Worth Lagoon North (LWN) includes the waters of the lagoon north of the Flagler Memorial Bridge in West Palm Beach. Lake Worth Inlet (also referred to as the Palm Beach Inlet) is the largest inlet and primary source of ocean water in the lagoon, and is also the primary outlet for fresh water. The flushing provided by the inlet has resulted in generally good water quality that supports the seagrass beds, and a small marine population of fish and shellfish.

The C-17 canal serves as the primary freshwater source for the lagoon, just south of Munyon Island, on the west side of the Intracoastal Waterway in North Palm Beach. The largest amount of mangroves in the lagoon is located here. There are also extensive seagrass beds in this area of the lagoon located in and around John D. MacArthur Beach State Park, Peanut Island, and south of Peanut Island, primarily along the western shores of the Intracoastal Waterway (PBC-ERM, 2006). Located within this section of LWN is the Port of Palm Beach (PPB) District, the fourth busiest port in Florida.

Lake Worth Lagoon Central

This segment includes the waters of the lagoon from the Flagler Memorial Bridge to Lake Worth Bridge. This section can range anywhere from a few hundred feet to nearly three quarters of a mile across, with depths up to 25 feet. Lake Worth Lagoon Central (LWC) is characterized primarily by single-family residences with armored shorelines, a sand and muck bottom with less seagrass coverage and scattered mangrove islands. The C-51 canal is the major source of fresh water as well as pollutants to the lagoon. To address these concerns Everglades restoration projects are expected to result in a reduction of freshwater discharges, thereby providing flood damage reduction benefits, improvements in water quality, and an increased water supply for the Everglades and other uses (PBC-ERM, 2006).

Lake Worth Lagoon South

The south segment includes the waters of the lagoon between Lake Worth Bridge and the Boynton Beach Bridge at Ocean Avenue. The South Lake Worth Inlet (otherwise known as Boynton Inlet) is 130 feet wide by 9 to 12 feet deep. It was initially opened in 1927 to increase circulation and improve water quality. In addition to abundant seagrass beds and mangroves, Lake Worth Lagoon South (LWS) also contains the Boynton (C-16) Canal, which is the primary source of freshwater discharges in this segment. There are also two small wastewater treatment plants that operate in Ocean Ridge (PBC-ERM, 2006).

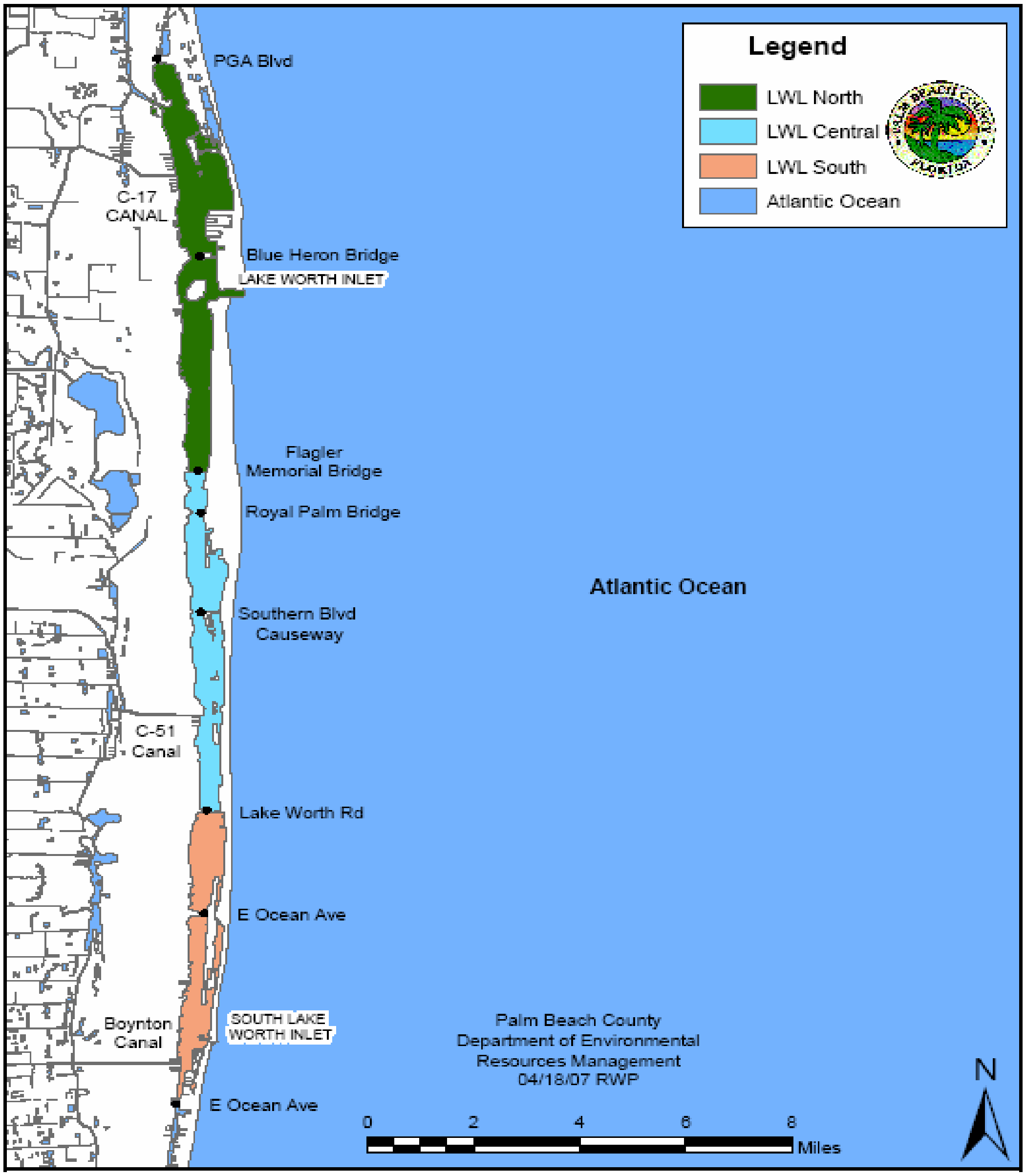


Figure 14. Segments of Lake Worth Lagoon.

In 2003, PBC-ERM and the U.S. Geological Survey entered into a multiyear cooperative agreement to investigate fluvial sediment transport in the C-51 canal, based on the use of surrogate technology. This project will involve the collection of water quality samples a short distance upstream of the S-155 control structure, along with concurrent collection of suspended sediment data using an optical backscatter sensor. In addition, sediment samples will be collected for analysis of shear stress and fall velocity and this data incorporated into a model developed by the District (see http://pubs.usgs.gov/of/2005/1394/).

The C-51 Sediment Management Project is an ongoing $2 million project based on a three-way inter-local agreement between Palm Beach County, the SFWMD, and the city of West Palm Beach. PBC-ERM manages the project and funding will be shared by Palm Beach County and the SFWMD. The muck is hydraulically dredged from the C-51 canal and transported via pipelines to thickening/decanting ponds. The muck is chemically dewatered and reduced to a cake-like consistency, then trucked away for use as a soil amendment by the Florida Department of Transportation and Palm Beach County. The water component is further treated (purified) in an on-site processing plant before being returned to the C-51 canal. The project began in May 2005 and will continue through 2008. Further information is available at http://www.pbcgov.com/erm/enhancement/c51.asp.

The CERP North Palm Beach County – Part 1 Project will have a significant positive impact on the future freshwater discharges to the lagoon. The project is developing performance measures for freshwater discharges to Lake Worth Lagoon and is evaluating redirection of flows and additional retention of storm water from the C-51 basin, and sediment removal and control technologies within the C-51 canal. Additional evaluations are focused on removal or trapping of existing sediment deposits in the lagoon downstream of the S-155 structure. The current status of this multiyear project is available at http://www.evergladesplan.org/pm/projects/project_docs/status/proj_17_current.pdf.

Recently there have been efforts by PBC-ERM to update the Lake Worth Management Plan and to develop a more integrated monitoring and assessment plan for the lagoon. PBC-ERM has taken the lead by preparing a new draft of the management plan (available at http://www.co.palm-beach.fl.us/erm/enhancement/lwlagoon.asp) and highlighting the current status of Lake Worth Lagoon collaborative efforts through coordination of a symposium presented on May 16, 2007.

PBC-ERM also has increased collaboration with The Restoration Coordination and Verification (RECOVER) process of CERP. The RECOVER Monitoring and Assessment Plan (MAP) prioritizes monitoring and assessment in order to evaluate CERP and provide recommendations for adaptive management actions. The CED staff is an integral part of the team that facilitates the collaboration of research and science initiatives between the two groups. Oyster monitoring under the auspices of RECOVER MAP has been initiated in Lake Worth Lagoon. Recent discussions have resulted in a cooperative agreement for enhanced water quality data collection and analysis between PBC-ERM and the District. More information is available online at http://www.evergladesplan.org/pm/recover/recover_docs/map/11_LWLbk.pdf.

Planned Activities

It will take several years for CED to develop a collaborative-based Science Plan for Lake Worth Lagoon. CED currently anticipates a continuation of the several projects that were started during the last twelve months, which should result in more robust dataset and the establishment of a framework for scientific assessment of LWL. Improved monitoring for water quality and biological resources under the auspices of the RECOVER Monitoring and Assessment Plan (MAP) in combination with continued efforts to identify sediment source, transport, and control technologies should provide the basis for developing a long-term framework for prioritizing scientific plans and assessment needs in the LWL watershed.

Without some future increase in the existing level of effort, CED staff will only be able to continue to provide technical review and support for ongoing CERP project and RECOVER activities. While it is anticipated that many existing information gaps relative to resource assessment and future enhancements of Lake Worth Lagoon will be addressed through investigations by PBC-ERM, RECOVER, and CERP North Palm Beach County Project – Part 1, development of an integrated CED Science Plan will require developing an appropriate research agenda and consistent assignment of scientific and technical resources to implement it. The CED will also continue to support the SFWMD Palm Beach Service Center, as requested. In addition, coordination and collaboration with PBC-ERM on routine planning, monitoring, and analysis activities will continue.

BISCAYNE BAY SCIENCE INVENTORY

Biscayne Bay is a large (~1,100 km^2; 426 sq mi), shallow (6 to 10 foot) subtropical estuary located in eastern Miami-Dade County, Florida. The northern half of the bay's coast is urbanized and bounded along the east by a series of barrier islands (see **Figure 15**). Biscayne National Park encompasses much of the southern half of the bay, and the shoreline is almost entirely mangrove forest. The Biscayne Bay watershed is about 2,400 square kilometers (939 mi^2) and contains the largest urban population (> 2.4 million; 2006 U.S. Census Bureau estimate) in Florida (Alleman et al., 2005). Agricultural lands are located mostly in the west and southwest portions of the watershed. The bay is characterized along much of its western shore by Miami's highly urbanized coast, while to the east the bay is delineated by a series of narrow, offshore barrier islands. A large portion of the bay is encompassed by Biscayne National Park, with the mainland shoreline housing the longest stretch of mangrove forest on Florida's east coast. Inland, hardwood hammocks grow with numerous native and nonnative floral species.

The bay, historically bounded by mangrove swamps and herbaceous wetlands, was hydrologically connected to the greater Everglades ecosystem through tributaries, sloughs, and groundwater flow. Construction of the Central and Southern Florida Flood Control (C&SF) Project, agricultural development, and urbanization have conspired to alter both the ecology and hydrology of the bay. Sheetflow, through sloughs and wetlands, submarine groundwater inflow, and runoff via tidal creeks have been reduced and largely replaced by pulsed, point source discharges from canals. Hydrologic connection with the greater Everglades has been severely constrained, and the total amount of fresh groundwater reaching the bay today is thought to be far less than in predevelopment times.

Historically, the bay included both estuarine and marine habitats. Today, the bay's estuarine habitats have been eradicated and/or reduced and are now mainly limited mostly into areas adjacent to or nearby canal outflows. These areas are subjected to extreme fluctuations in salinity associated with the pulsed delivery of fresh water from canals.

Today the bay is largely marine, and the central and southern regions are characterized by clear ocean waters. Because the bay is shallow, its productivity is largely benthic-based. The estuary's dominant benthic components in the central and southern regions include six seagrass species, hardbottom communities including corals (hard and soft) and sponges, attached and drift macro-algae, and coral-algal fringe.

Exchange with the ocean is more restricted in the northern portion of the bay. Here the increased stormwater runoff associated with urbanization has measurably increased turbidity and nutrient concentrations relative to regions further south. While seagrasses cover significant portions of the northern bay, the nearshore benthos has been disturbed via historical dredge-and-fill projects, and shoreline bulkheads and the opening of two major inlets many years ago.

All portions of the bay support commercial and recreational fisheries and provide habitat for a number of threatened and endangered marine species. In recognition of its exceptional value, the state of Florida has designated the bay and its natural tributaries as Outstanding Florida Waters, and as such, they receive the highest level of protection from degradation. The bay was designated as an Aquatic Preserve by the Florida legislature in 1974, and a draft management plan was developed but never adopted. The bay was also designated as an Aquatic Park and Conservation Area by the Miami-Dade Board of County Commissioners. Biscayne National Park was established in 1980 and the Florida Keys National Marine Sanctuary in 1990.

Detailed quantitative information on specific urban impacts is essential to effectively guide management decisions related to future growth, development and consumptive uses in and around Biscayne Bay. Major water resource issues are posed in the near term, not only by CERP, but also by many pre-existing activities and obligations.

A series of CERP projects which include the Biscayne Coastal Wetlands Project, the C-111N Spreader Canal Project, the Levee-31 North Seepage Management Project, the Lake Belt Project, the West and South Miami-Dade Water Reuse Project, the Water Conservation Area Decompartmentalization Project, and the C-9 Basin Broward County Water Preserve Area Project could directly affect Biscayne Bay water supply and water quality. Other CERP projects which could indirectly affect Biscayne Bay water supply include the Water Conservation Area Decompartmentalization Project. In addition, planned projects such as the Lower East Coast Regional Water Supply Plan, Minimum Flows and Levels (MFL) criteria, and the Flooding Task Force's charge to enhance flood protection for Miami-Dade County all could affect Biscayne Bay. To address these possibilities, CERP's Adaptive Assessment Team (AAT) has developed a risk assessment conceptual model specifically for Biscayne Bay, and has been tasked with specifying performance measures and requisite monitoring needs for the bay as they relate to CERP implementation.

Each of these activities has significant scientific information needs. For example, the development of MFL criteria for Biscayne Bay requires quality information and tools that relate freshwater inflow to salinity and biological resources. Currently, CED scientists, in collaboration with the water supply staff, are preparing a technical document summarizing the relevant, available scientific information and modeling tools that can be used to relate basin-level freshwater flows to living resources in Biscayne Bay. Following a peer review the District will either proceed with rule development or implement a program to fill data and modeling gaps.

Several information gaps and research and monitoring needs have already been identified (cf. the 2002 Strategic Science Plan for Biscayne Bay; Alleman et al., 2002). For example, although seagrasses have been monitored in some areas for more than 20 years, there is a paucity of data in critical areas such as the western nearshore area within the southern region. These data are needed to determine whether and how species abundance and distribution patterns (many currently unknown) change in relation to salinity dynamics. Critical spatial gaps still exist in salinity data, especially in the southern nearshore zone and adjacent wetlands. Also important for MFL criteria analysis is an understanding of freshwater fluxes. Current understanding is that the majority of fresh water enters Biscayne Bay through a series of gated canals, where flows are estimated based on water stage. The precision of these estimates is uncertain, although and in some cases, estimates are may be 20 percent different than measured flows. Groundwater contributions are a relatively small percentage of freshwater inputs compared to canal flow and rainfall but may be a significant source of fresh water in some areas where groundwater flux is large, and also during the end of the dry season. However, very little information has been collected about the spatial distribution, rates of groundwater flux, and the quantity or quality of the groundwater in the bay.

Planned Activities

Our strategy for Biscayne Bay science includes the application of the integrated modeling and assessment framework, as previously outlined in this document, to formulate a detailed science plan and design and implement projects to fulfill the identified data and modeling gaps in Biscayne Bay. To this end the CED has begun a pilot study to (1) assess the distribution of submarine freshwater springs and their impact on the water quality and ecology of the bay, (2) assess the effects of canal discharges on nearshore salinity and seagrass habitat, and (3) monitor a soft coral garden located in Biscayne National Park. The garden is atypical, in that it is dominated by marine macro-algae and soft corals; species from both groups have the potential to serve as indicator species of salinity change.

Table 9 describes recently completed and ongoing projects, and scientific products which allow the CED to increase our understanding of Biscayne Bay and its watershed and improve water management decisions.

In FY2008, the Coastal Ecosystems Division plans to:

1. Design and implement an experimental field study to examine the groundwater flow impacts on chemistry and ecology within Biscayne Bay.
2. Conduct hydroacoustic benthic habitat assessments to quantify the affect of management derived alteration of nearshore salinities on seagrass and other species distributions and responses.
3. Synthesize water quality, hydrological and ecological data sets in Biscayne Bay to examine statistically significant relationships (spatially and temporally) between them.
4. Complete a habitat suitability index for fishes utilizing the southwest shoreline of Biscayne Bay.
5. Complete a peer-reviewed science plan for Biscayne Bay.
6. Develop a CH3D hydrodynamic model for Biscayne Bay.

Future Information Needs

1. Water quality models to estimate pollutant loadings from the watershed and to predict water quality patterns in the bay.
2. Ecological models to evaluate estuarine response to water management practices.
3. Groundwater baseline data and studies on effects of groundwater on estuarine resources.
4. Coastal wetland projects to understand the existing character.

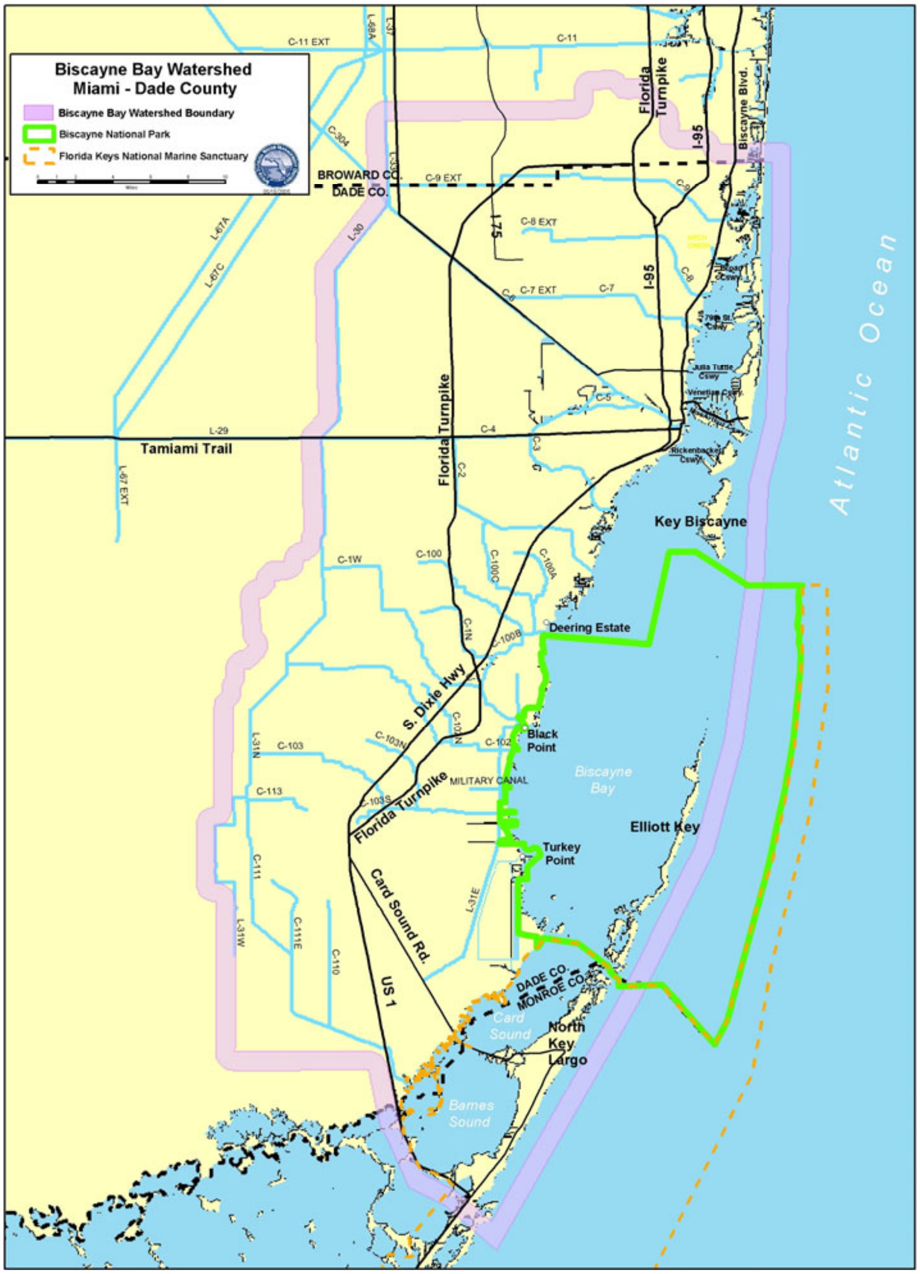


Figure 15. Biscayne Bay, showing major canals and boundaries of Biscayne Bay National Park.

Table 9. Recently completed and ongoing projects for Biscayne Bay.

Water Body	Study Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Milestone	Contract PIs/Co-PIs
Watershed/Groundwater Modeling							
Biscayne Bay	Biscayne Bay Integrated groundwater and surface water model and analysis of the hypersalinity events in southwestern Biscayne Bay	Richard Alleman	2005-2007	USGS	Investigate the cause of hypersalinity events observed in south central Biscayne Bay. The model will be used to perform hydrogeologic investigations to determine if, and how changes in shallow groundwater flow are affecting Biscayne Bay salinities near-shore salinity.		Melinda Wolfert and Chris Langevin (USGS); John Wang (University of Miami)
Ecological Modeling							
Biscayne Bay	Development of habitat suitability models for the southwest shoreline Biscayne Bay area fishes	Richard Alleman	2007-2008	NOAA-NMFS	Develop habitat suitability index (HSI) models using existing empirical fish abundance data. Emphasis will be placed on revealing abundance-salinity relationships for selected fish taxa via the analysis of multiple datasets collected from Biscayne Bay and adjacent systems. Relationships between salinity and community-level indices (e.g., diversity, trophic and taxonomic groupings) will also be investigated.		Joe Serafy (NOAA-National Marine Fisheries Service)
VEC Assessment							
Biscayne Bay	Current and Past Distribution of Oysters in Biscayne National Park	Richard Alleman	2006-2007	SFWMD	Estimate current abundance and distribution of Eastern oysters along the western shoreline of BNP, and determine location and extent of historical oyster bars.		Sarah Belmund (BNP)
Biscayne Bay	Nearshore Epibenthic Cover in Southern Biscayne Bay	Richard Alleman	2003-2004	SFWMD	Documented baseline distribution and abundance of seagrass species within one kilometer of the southwest shoreline from Shoal Point to US 1.		Juliet Christian, John Meeder, and Amy Renshaw (FIU)
Biscayne Bay	Historical Changes of Salinity, Water Quality and Vegetation Changes in Biscayne Bay	Richard Alleman	2002-2004	USGS	Examined historical changes in the Biscayne Bay ecosystem in broad context at selected sites on a decadal to centennial scale, and to correlate these changes with natural events and anthropogenic alterations in the South Florida region. Specific emphasis will be placed on historical changes to (1) amount, timing, and sources of freshwater influx and the resulting effects on salinity and water quality; (2) shoreline and sub-aquatic vegetation; and (3) the relationship between sea-level change, onshore vegetation, and salinity.		Lynn Wingard and others (USGS, Reston, VA)

Table 9. Continued.

Water Body	Study Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Milestone	Contract PIs/Co-PIs
Biscayne Bay	Biscayne Bay Feasibility Study	Richard Alleman	1996-2003	USACE	This study is a partnership between the USACE and Miami-Dade County numerical model study. It was proposed and undertaken primarily to develop numerical modeling tools to aid in the further assessment of the impact of federal projects on Biscayne Bay and other features on the system. Particular emphasis was placed on the use of the tools to assess the impact of changing freshwater inflows on the hydrodynamics and salinity of the bay. The SFWMD has assisted with funding and also maintains one of the modeling products on its servers.		Gary Brown and others (Coastal Hydraulics Laboratory, USACE)
Biscayne Bay	Biscayne Bay Coastal and Nearshore Community Baseline Study to Develop Biological Performance Measures	Richard Alleman	2002-2005	NMFS	Broad objectives of this southern Biscayne Bay project were: (1) to characterize the spatial and temporal patterns of fish and macroinvertebrate density and diversity in the mainland nearshore zone and coastal wetlands, (2) to evaluate the relationship of variability in shrimp catch rates of commercial vessels operating in the commercial fishing zone with shrimp densities in fished versus unfished seagrass habitats, (3) to examine trends in commercial pink shrimp fisheries in relation to freshwater inflow and salinity, and (4) to evaluate relationships between fishes using mangrove fringe habitats and the abundance and diversity of fish and macroinvertebrates in adjacent seagrass habitats.		Joan Browder (Southeast Fisheries Science Center, NMFS), Michael Robblee (USGS), Jerome Lorenz (National Audubon)
Biscayne Bay	Salinity Relationships of Epifaunal Species in Near-Shore Biscayne Bay	Teresa Coley	2006-2009	SFWMD	Investigate the effects of different salinity and temperature exposure scenarios on pink shrimp (*Farfantepenaeus duorarum*) collected from Biscayne Bay. Optimum salinity and temperature conditions will be defined for performance measures (i.e. survival, development, growth).		Gray Rand (FIU)
Biscayne Bay	Large-scale remotely sensed SAV monitoring program. Southern Estuaries Module: Biscayne Bay SAV Photointerpretation	Teresa Coley	2007-2008	SFWMD	Assess current seagrass distribution, abundance, and spatial patterns in Biscayne Bay and provide and provide current benchmarks against which the effects of hydrologic restoration activities can be measured by producing good quality maps of SAV coverage and extent in Biscayne Bay.		Photoscience Inc.(tentative)

Table 9. Continued.

Water Body	Study Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Milestone	Contract PIs/Co-PIs
Biscayne Bay	Submerged Aquatic Vegetation data analyses	Teresa Coley	ongoing	SFWMD	Synthesize submerged aquatic vegetation data and determine effects of freshwater inflow and salinity in Biscayne Bay.		
Biscayne Bay	Large-scale Remote-Sensed SAV Monitoring Program	Teresa Coley	2006-2007	SFWMD	Georeference, orthorectification, and mosaicing of 2005 digital aerial photographs of Biscayne Bay for purposes of assessing current seagrass distribution, abundance, and spatial patterns in Biscayne Bay and provide current benchmarks against which the effects of hydrologic restoration activities can be measured by producing good quality maps of SAV coverage and extent in Biscayne Bay.		Kevin Madley (FMRI)
Watershed							
Biscayne Bay	Wetlands Inventory for the Biscayne Bay Coastal Wetlands Project Area	Richard Alleman	2003	SFWMD	Updated National Wetlands Inventory classification of land cover in the southeast watershed. (Biscayne Bay Coastal Wetlands Project National Wetlands Inventory Update)		Miller Legg
Biscayne Bay	Restoration of the Black Creek Coastal Wetlands and Nearshore Estuarine Zone in Biscayne Bay	Richard Alleman	2002	SFWMD	Examined the suitability of rehydrating the coastal wetlands near Black Point, the nearshore zone and determined water inflow targets.		John Meeder and others (FIU)
Scientific Products							
Biscayne Bay	Technical Documentation to Support Development of Minimum Flows and Levels for South-Central Biscayne Bay	Richard Alleman	2005	SFWMD	An initial draft that documented the information, methods and assumptions used by the District to develop minimum flow technical criteria for south-central Biscayne Bay.		Rick Alleman
Biscayne Bay	Final report on literature review of the effects of salinity levels and variations on Biscayne Bay biological resources	Teresa Coley	ongoing	SFWMD	Conduct a comprehensive literature review pertaining to salinity dosing effects on species identified potential indicator species that are documented in Biscayne Bay.		Lewis Environmental, Inc.
Biscayne Bay	Summary of Statistical Relationships between Hydrology of the Eastern C-103 Basin and Nearshore Salinity in Biscayne Bay	Richard Alleman	2006+	SFWMD	Develop statistical models to explore how groundwater and surface water hydrology of the C-103 basin might affect nearshore salinity in Biscayne Bay.		Rick Alleman

CALOOSAHATCHEE ESTUARY AND LOWER CHARLOTTE HARBOR SCIENCE INVENTORY

The Caloosahatchee River runs from Lake Okeechobee to the Franklin Lock and Dam (S-79) (see **Figure 16**). The River is the major source of fresh water for the Caloosahatchee Estuary which runs 42 kilometers from S-79 to Shell Point, where it empties into San Carlos Bay. The river bisects its watershed and now functions as a primary canal (C-43) that conveys both runoff from the Caloosahatchee watershed and regulatory releases from Lake Okeechobee. The canal has undergone a number of alterations to facilitate this increased freshwater discharge and flood protection. These alterations include channel enlargement, bank stabilization, the development of an intricate network of canals within the watershed, and the addition of three lock and dams. The final downstream structure, Franklin Lock and Dam (S-79), demarcates the beginning of the estuary, and acts as a barrier to salinity and tidal action, which historically extended to nearly the LaBelle area.

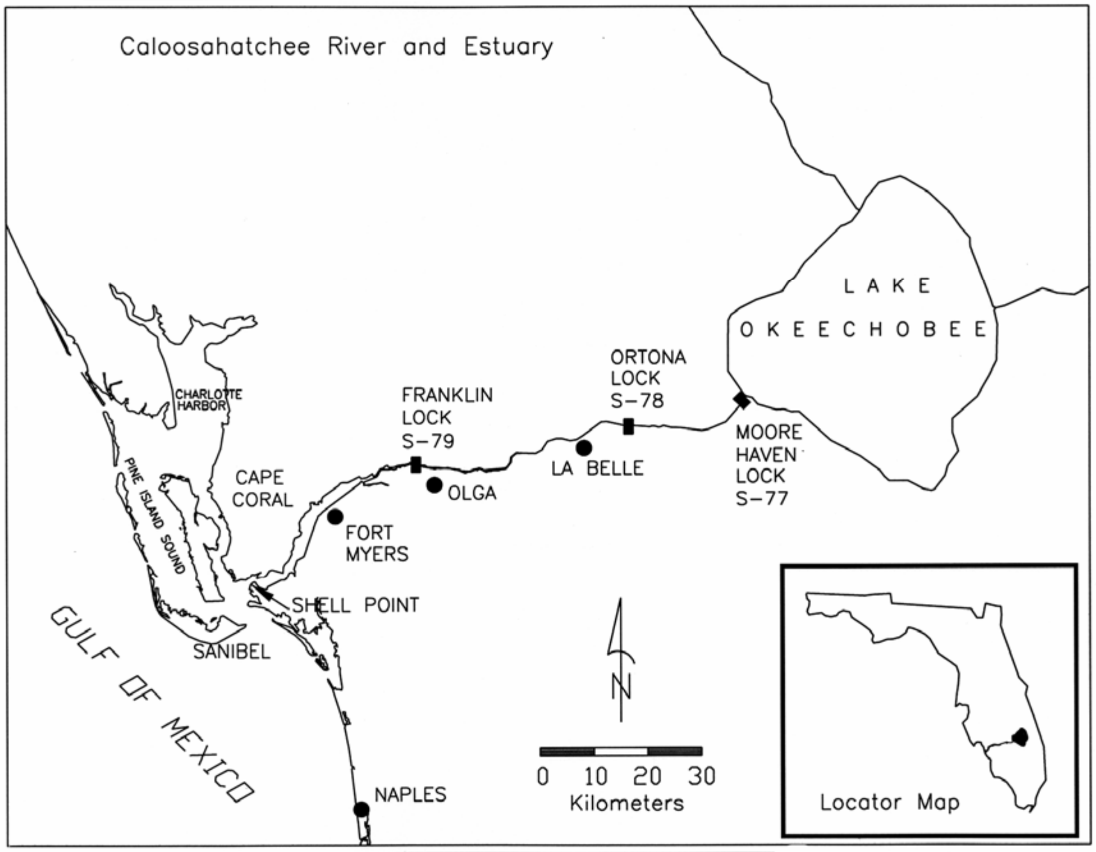


Figure 16. Caloosahatchee River and Estuary.

The alterations to the Caloosahatchee River and watershed have resulted in a drastic change in freshwater inflow to the downstream ecosystem. During the wet season, high flows can turn much of the system fresh, while lack of freshwater inflow during the dry season results in significant saltwater intrusion. The resulting large fluctuation of salinity adversely impacts estuarine biota (Chamberlain and Doering, 1998a; Sklar and Browder, 1998).

The purpose of the research program in the Caloosahatchee has always been to inform regulatory and inflow management initiatives. Early work was field oriented and exploratory. In the 1990s, field and laboratory experiments were conducted to establish cause and effect relationships between changes in salinity and biotic responses. Initial efforts at hydrodynamic modeling also began. More recently, ecological modeling of SAV has begun.

Initial research in the Caloosahatchee Estuary began in the mid-1980s and focused on quantifying the effects of freshwater inflow on estuarine biota. Initial phases of the research observed the estuary seasonally and under different inflow conditions in each season (see **Figure 17**). Sampling targeted benthic macro-infauna, zooplankton, phytoplankton, ichthyoplankton, submerged aquatic vegetation, and water quality (including nutrients and chlorophyll). Sampling stations spanned the region between S-79 and Pine Island Sound (**Figure 16**).

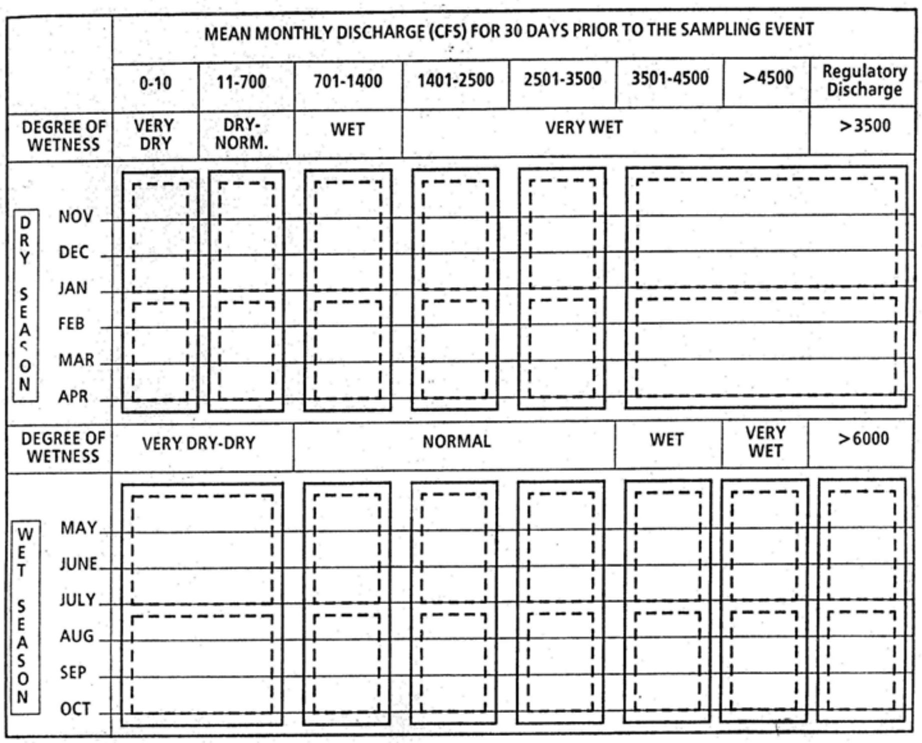


Figure 17. Initial design of field sampling of the Caloosahatchee Estuary. Mean monthly flows calculated at the Franklin Lock and Dam (S-79).

In addition to these extensive field observations of estuarine biota, laboratory mesocosm experiments and field experiments were conducted to establish salinity tolerances. Development of salinity–inflow relationships that have evolved from statistical regressions to three-dimensional, numeric hydrodynamic/salinity models (CH3D). Summaries of that research may be found in Bierman, 1993; Chamberlain et al., 1995; Chamberlain and Doering, 1998 a,b; Kraemer et al., 1999; Doering and Chamberlain, 2000; Bortone and Turpin, 2000; Doering et al., 2002; SFWMD, 2000; SFWMD, 2003, Volety et al., 2003; Sheng, 2004.

The basic approach to establishing freshwater inflow requirements involved four steps: the first was to select VEC; the second was to quantify the salinity tolerances of the VEC; the third was to develop relationships between freshwater inflows and salinity; and the fourth was to determine the flows that will position tolerable salinities in the regions where the VEC exists. The freshwater SAV *Vallisneria americana* serves as a VEC for the upper estuary; the eastern oyster, *Crassostrea virginica*, for the middle or mesohaline regions of the estuary; and the seagrasses *Halodule wrightii* and *Thalassia testudinum*, for the higher salinity marine regions. One assumption of this approach is that, if salinity conditions are tolerable for VEC, they will also be tolerable for other organisms. Using the extensive field observations and additional information from the literature Chamberlain and Doering, 1998b, showed that inflows tolerated by SAV could also be tolerated by a wide variety of other biota.

Initial application of research results was to the determination of a minimum flow and level (MFL) for the Caloosahatchee River and Estuary (SFWMD, 2000). From statistical regressions of flow on salinity, it was determined that a minimum mean monthly inflow of at least 300 ft^3/sec (cfs) was needed from S-79 to ensure that the average monthly salinity at Fort Myers (Yacht Basin) is < 10 ppt (target maximum salinity for tape grass) and daily average salinity does not exceed 20 ppt. Hydrodynamic modeling indicated that a total inflow of about 450 cfs was required to meet the salinity criteria. Information from a watershed model of the tidal basin indicated that during normal times, the additional 150 cfs came from the tidal basin. During dry times, this additional input is not available from the tidal basin and must be supplied at S-79 to maintain appropriate salinity (SFWMD, 2003a).

At the other extreme, mean monthly flows that exceed 2,800 cfs should be minimized, because greater flows cause more than half the estuary upstream of Shell Point to become fresh water and salinity near Shell Point drops to levels that threaten many of the species in this region (Chamberlain and Doering, 1998b; Doering et al., 2002). Mean monthly inflows greater than 4,500 cfs from S-79 cause salinity in San Carlos Bay to decline below desired levels and the entire estuary upstream of Shell Point to approach freshwater conditions.

The salinity criteria for the MFL are intended to protect beds of *Vallisneria* in the upper estuary. A numerical *Vallisneria* model (Hunt and Doering, 2005) was developed to evaluate the effectiveness of various engineering solutions at protecting this resource. For example, the effect of proposed CERP projects on the long-term (30-year) viability of *Vallisneria* in the upper estuary was evaluated. In this application, a linked model approach was used. Discharge at S-79, estimated from the South Florida Water Management Model was used as input to the hydrodynamic model (SFWMD, 2003a). The salinity output from the hydrodynamic model was used as input to the *Vallisneria* model. The *Vallisneria* model was also used to help interpret data collected from the field and identify the factor(s) most responsible for observed declines in density of *Vallisneria* (e.g.: salinity, light, or temperature).

One goal of research on the freshwater requirements of the Caloosahatchee was to establish a frequency distribution of flows that could be used as a hydrologic target for various projects including the CERP C-43 Basin Storage Reservoir Project, the Southwest Florida Feasibility Study, and the Northern Everglades Protection Plan. As a first attempt to define this environmentally sensitive distribution of S-79 discharges, an optimization model was employed (Labadie, 1995; Otero et al., 1995). The model used historic watershed runoff data during 1966–1990 (without regulatory Lake Okeechobee discharges). The initial distribution frequencies (Chamberlain et al., 1995; Chamberlain and Doering, 1998b) were further refined during the restudy to consider MFL requirements for achieving estuarine resource protection. Most recently, estimates of tidal tributary inflows were added to better assess total estuarine inflows related to salinity distribution targets, which lead to the selection of EST05 daily time series as the preferred distribution (see **Table 10**) (SFWMD, 2003b).

Table 10. The preferred frequency distribution of mean monthly flows from S-79 (without tidal basin contribution) derived from the daily time series of discharges know as EST05.

Discharge Range (cfs) from S-79	Percent Distribution of Flows from S-79
0 to 450	0%
450 to 500	42.8%
500 to 800	31.7%
800 to 1500	19.2%
1500 to 2800	5.6%
2800 to 4500	0.7%
>4500	0%

In addition to water quantity, water quality has been a concern in the Caloosahatchee. In fact, waste load allocation studies conducted more than twenty years ago in the Caloosahatchee Estuary by the Florida Department of Environmental Regulation (DeGrove, 1981) concluded that the estuary had reached its nutrient loading limit as indicated by elevated chlorophyll *a* and depressed dissolved oxygen levels. Recent research has concentrated on quantifying nutrient loads (Janicki, 2003; Doering and Chamberlain, 2005; Crean and Iricanin, 2005) and has culminated in a Watershed Management Model (Camp Dresser and McKee, 2007). Other efforts have concentrated on setting water quality targets (Corbett and Hale, 2006) and identifying indicators of eutrophication (Doering et al., 2006). Some recent and ongoing studies are listed in **Table 11** below.

Table 11. Recent and ongoing studies in the Caloosahatchee Estuary.

Water Body	Study Title	Point of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Plan Milestone
			Hydrodynamic Modeling			
Caloosahatchee	Graphical User Interface for CH3D Model	Chenxia Qiu	2007	District	Update GUI to run on ARC-GIS Platform.	Northern Everglades Protection Plan
			Water Quality			
	Nutrients in the Caloosahatchee	Peter Doering	2006-2008	District	Assess nitrogen and phosphorus limitation of phytoplankton growth in the Caloosahatchee.	Northern Everglades Protection Plan
			VEC Assessment			
Caloosahatchee	Tapegrass Temperature Tolerance	Melody Hunt	2006-2008	District	Develop a series of temperature growth curves for *V. americana* derived from CE in mesocosms. Information to be used in updates to the Val. numerical model.	CERP /RECOVER/Northern Everglades
Caloosahatchee	SAV and Faunal Relationships with regard to salinity and seasonality - Contract CP050281	Dan Crean	2004-present	District	Results of this research will provide information applicable to restoration and management efforts, with the goal of incorporating research-derived predictions of changes in community structure associated with habitat changes.	Freshwater Inflow Studies
Caloosahatchee	Blue Crab/Salinity assessment in the Caloosahatchee River Contract OT050973	Dan Crean	2004-2007	District	Crab pot movement as it relates to fresh water inputs into the Caloosahatchee River Estuary	Freshwater Inflow Studies
Caloosahatchee	Hydro-acoustic SAV Monitoring	Bob Chamberlain	1995-present	District	Monitor SAV in Estuary, San Carlos Bay, and Pine Island Sound.	Freshwater Inflow Studies
			Watershed			
Caloosahatchee	WMM	Stormwater Management Division	2007	District	Land Use-based Loading Model	

Planned Activities

1. Continue the efforts identified for FY2008, as needed, including the further movement toward a more sophisticated water quality collection network with real-time data and assessment capability. This should be part of a cooperative effort with Lee County, Florida Department of Environmental Protection and other parties. Areas of special interest, where the District should focus its contributions are: (a) real-time hydrologic data collection in the tidal tributaries (currently an unknown quantity); (b) collection of real-time DO to determine if state standards are violated; (c) the collection of real-time light intensity at key SAV bed locations to determine average daily bottom light requirements of SAV and when and why they are not achieved; and (d) the development of a better water quality collection network that more frequently collects samples, better suited for the detection of change (trends), and also supports the development of an estuarine water quality model.
2. Develop ecosystem modeling tools for the VECs and other key biota in order to predict impacts due to water management decisions both in the short term, associated with real-time freshwater releases, and the long term, associated with aforementioned mandated projects and programs.
3. Complete a dynamic watershed and estuarine water quality model, which can then be used to determine the impacts from changing water management practices and cause changes in nutrient loading and the inflow of other important water chemistry constituents.
4. Development of quick-recommendation tools that utilize ecosystem models in conjunction with freshwater inflows and output of the water quality model. These tools will be used to provide better science-based recommendations to water managers considering freshwater release for flood protection, water supply, or environmental benefit.

ESTERO BAY SCIENCE INVENTORY

Data collection in Estero Bay began in 2003 to support development of a minimum flow and level for that system. Estero Bay (see **Figure 18**) is a small, shallow bar-built estuary located on the southwest coast of Florida. As a bar-built system, Estero Bay is dynamic. Opening, closing, and migration of inlets due to storms and long-shore erosion and deposition have been documented. Based on tidal circulation, the Estero Bay Marine Laboratory has recognized five distinct zones within the bay. Surficial freshwater inflow comes from five major creeks that are distributed along the eastern shore of the bay. From north to south these are Hendry Creek, Mullock Creek, the Estero River, Spring Creek, and the Imperial River. While four of the five creeks empty into the main body of the estuary, the influence of the Imperial River may be limited to the most southern reaches of the bay. Much of the flow from this river may enter the Gulf of Mexico quickly through Big Hickory Pass.

Issues of concern in Estero Bay center on the potential effects of increased development in the watershed. Prominent among these are degraded estuarine water quality, altered freshwater inflow, altered sedimentation, and loss of biotic resources, such as seagrass beds and oyster bars. Despite several studies of water quality, seagrass beds, and circulation, there is a lack of scientific information concerning Estero Bay. With continued development in the watershed and the opening of Florida Gulf Coast University, scientific investigation of Estero Bay is increasing. However, perceptions of environmental degradation such as loss of seagrass beds and events of low dissolved oxygen remain anecdotal or have not been tied to anthropogenic disturbance.

In Florida, the purpose of a minimum flow or level is to ensure that no significant harm comes to the water resources or ecology of an area such as Estero Bay. Establishing an MFL requires an understanding of the connections between freshwater inflow, estuarine conditions (salinity) and resources (distribution and abundance of organisms). Although review continues, not much existing information appears directly applicable to establishing MFLs. Some historical records for freshwater inflow exist, but there is little information that relates freshwater inflow to salinity in Estero Bay. Further, no studies have been found to quantify the responses of Estero Bay biota to changes in salinity or freshwater inflow. Outlined is a series of completed, ongoing, and projected studies which should allow us to (1) learn more about the history and general ecology of Estero Bay, (2) define relationships between freshwater inflow and salinity, (3) examine the responses of several estuarine species, or groups of species, to freshwater inflow/salinity, and (4) select and apply an appropriate method for establishing an MFL.

Setting an MFL in a lagoonal system, such as Estero Bay, presents unique challenges. The bay does not have a single dominant source of fresh water, but several that are distributed along the eastern shore. An MFL for the lagoon could be established, but the total minimum flow would have to be apportioned between the five sources. Since each tidal creek comprises a small sub-estuary of the larger Estero Bay system, an MFL could be established for each creek. Would the total of these minimum flows be enough to protect the bay proper? The ecological studies summarized below will allow us to learn both about the bay and its tributaries, and the effects of freshwater inflows on their biota.

Planned Activities

The planned activities for Estero Bay are summarized in **Table 12**. To date, projects have centered on developing a CH3D hydrodynamic/salinity model and evaluating various organisms or groups of organisms as potential VEC. A land use-based nutrient loading model (WMM) was developed by the District's Stormwater Division.

In FY2008, the Coastal Ecosystems Division plans to:

1. Extend the CH3D hydrodynamic model into the tributaries
2. Synthesize juvenile fish data, i.e., determine effects of freshwater inflow and salinity.

Future Information Needs

1. More detailed watershed model (such as WaSh) that route flows to the bay and support a water quality module.
2. Water quality projects

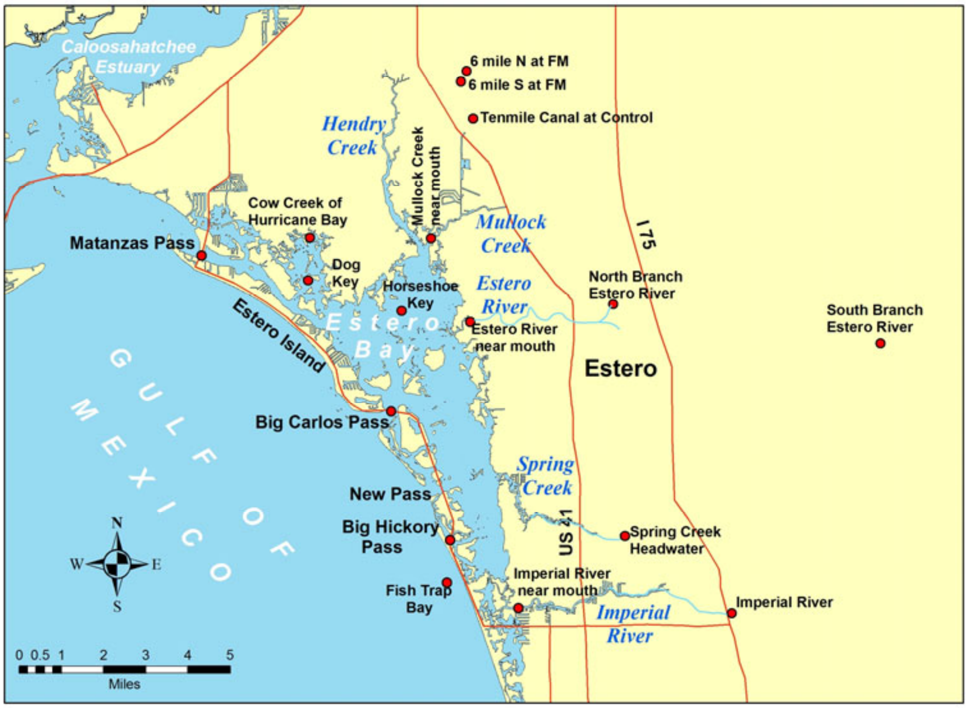


Figure 18. Estero Bay showing major passes and tidal creeks. Red dots are USGS monitoring stations maintained from 2001–2006.

Table 12. Science Program for Estero Bay.

Water Body	Study Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Plan Milestone
			Hydrodynamic Modeling			
Estero Bay	USGS Estero Bay WQ Data Collection C-15171	Bob Chamberlain	2001-2007	USGS	Salinity, current, water elevation data collected at 9 stations to support development of CH3D hydrodynamic model	Freshwater Inflow Studies
Estero Bay	Bathymetry	Tomma Barnes	2003	USGS/District GIS	Determine Bathymetry of Estero Bay to support Hydrodynamic Model	Freshwater Inflow Studies
Estero Bay	Bathymetry	Tomma Barnes	2004-2005	District GIS	Determine Bathymetry of Estero Bay tributaries to support Hydrodynamic Model	Freshwater Inflow Studies
Estero Bay	Hydrodynamic Model	Chenxia Qiu	2006	District GIS	Calibrate CH3D Model for Estero Bay	Freshwater Inflow Studies
			VEC Assessments			
Estero Bay	Hydrologic History of Estero Bay	Robert Chamberlain	2003-2004	District	Paleo-ecological study of Estero Bay to reconstruct environmental conditions over the long term and short term	Freshwater Inflow Studies
Estero Bay	Molluscs as Indicators of Environmental Change in South Florida Estuaries	Peter Doering	2003	District	Summary of salinity and temperatures at which various molluscs were collected	Freshwater Inflow Studies
Estero Bay	Aerial Mapping of Oyster Reefs	Tomma Barnes	2003	District	Map Distribution of Oysters	Freshwater Inflow Studies
Estero Bay	Freshwater Inflow and Nursery Function of Estero Bay	Peter Doering	2004-2007	District	Quantify relationships between salinity/freshwater inflow and larval fish	Freshwater Inflow Studies
Estero Bay	Juvenile Fish Monitoring	Robert Chamberlain	2004-2007	FWRI	Quantify relationships between salinity/freshwater inflow and juvenile fish	Freshwater Inflow Studies
Estero Bay	Bivalve Transects	Beth Orlando	2004-2006	District	Quantify relationships between salinity/freshwater inflow and bivalved molluscs	Freshwater Inflow Studies
Estero Bay	Hydro-acoustic SAV Assessment	Robert Chamberlain	2006-	District	Survey seagrasses to quantify distribution and response to freshwater inflow	Freshwater Inflow Studies
Estero Bay Tributaries	Bivalve Transects	Beth Orlando	2007-	District	Quantify relationships between salinity/freshwater inflow and bivalved molluscs in tributaries	Freshwater Inflow Studies
Estero Bay Tributaries	Oyster Response to Tributary Inflow	Dan Crean	2006-2007	District	Utilization of Creek Mouth oyster beds by fish	Freshwater Inflow Studies
Estero Bay Tributaries	Shoreline Mapping	Peter Doering	2006-2007	District	Distribution of shoreline vegetation to determine freshwater/saltwater interface in tributaries	Freshwater Inflow Studies
			Watershed			
Estero Bay	WMM	Stormwater Division	2007	District	Land Use-based Loading Model	

NAPLES BAY SCIENCE INVENTORY

Naples Bay is a relatively narrow and shallow estuarine system (see **Figure 19**). Its width ranges from 100 to 1,500 feet, and its depth varies from 1 to 13 feet. It is formed by the confluence of the Gordon River and other small tributaries that empty into the Gulf of Mexico through Gordon Pass. Dollar Bay, the portion of the Naples Bay system south of Gordon Pass, is connected to Rookery Bay through a shallow waterway with a dredged channel.

Naples Bay is typical of estuarine systems along the coast of Florida that have been heavily altered by drainage, agriculture, and urban development. Therefore, water clarity and water quality, freshwater inflows, and natural habitats are largely impacted by human activities and are considerably different from their historic conditions.

The first recorded human disturbance in Naples Bay was a canal that was excavated by the indigenous people inhabiting these waters over 2,000 years ago. The construction of the pier in the late 1880s permitted steamships to transport freight and passengers to Naples. The completion of the Tamiami Trail (i.e., U.S. Highway 41) in 1926 set in motion the urban development that now surrounds Naples Bay. Two major disturbances occurred between the 1950s and 1960s. In the early ’50s, dredge and fill operations began the transformation of the mangrove swamps of Naples Bay into waterfront canal home sites, such as the community development of Aqualane Shores, Port Royal, and Royal Harbor. In the ’60s, the construction of the Golden Gate Canal system increased the Naples Bay watershed from 10 sq mi to 130 sq mi, resulting in a 20-40 times increase in freshwater inflow (Schmid and Zimmerman et al., 2006).

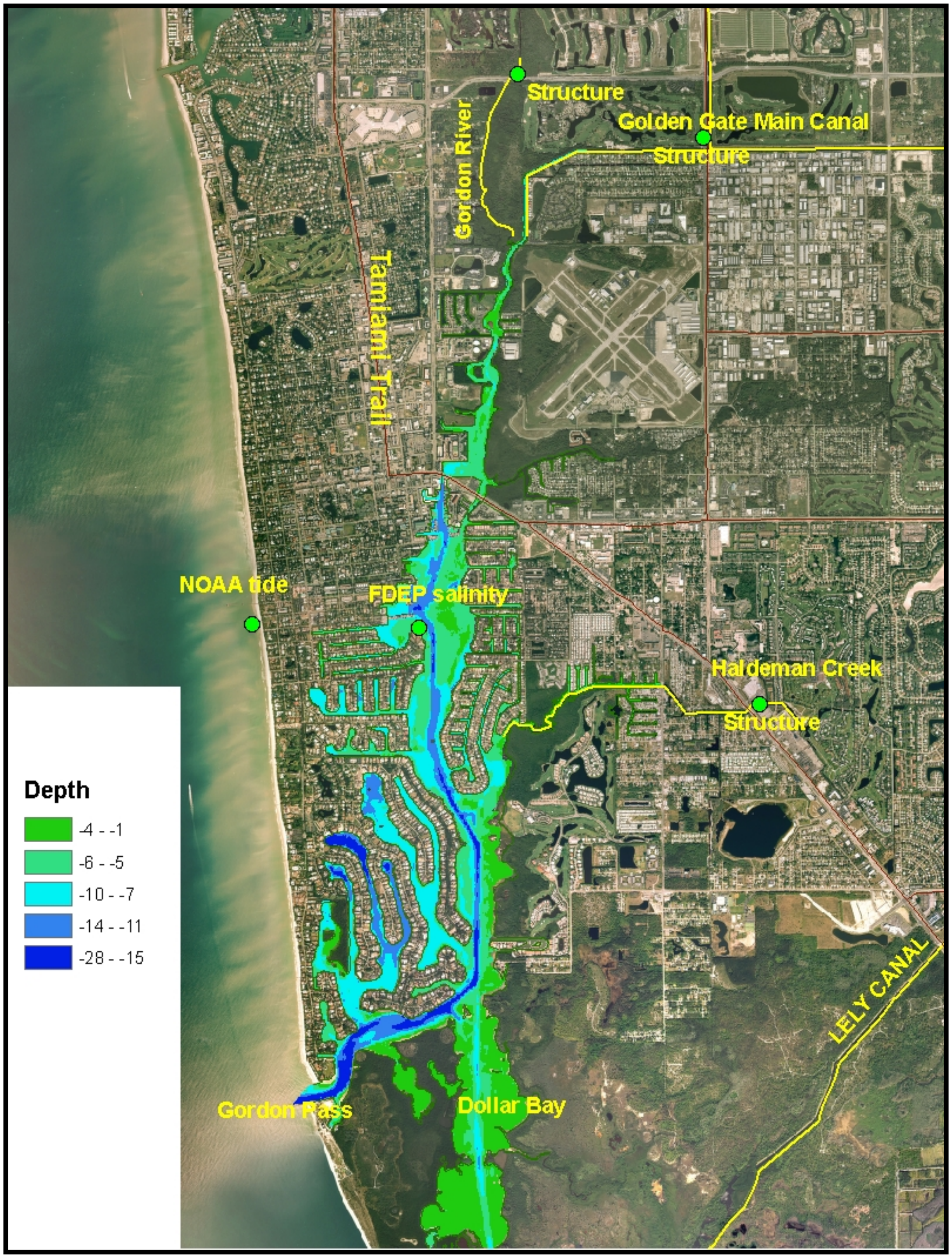
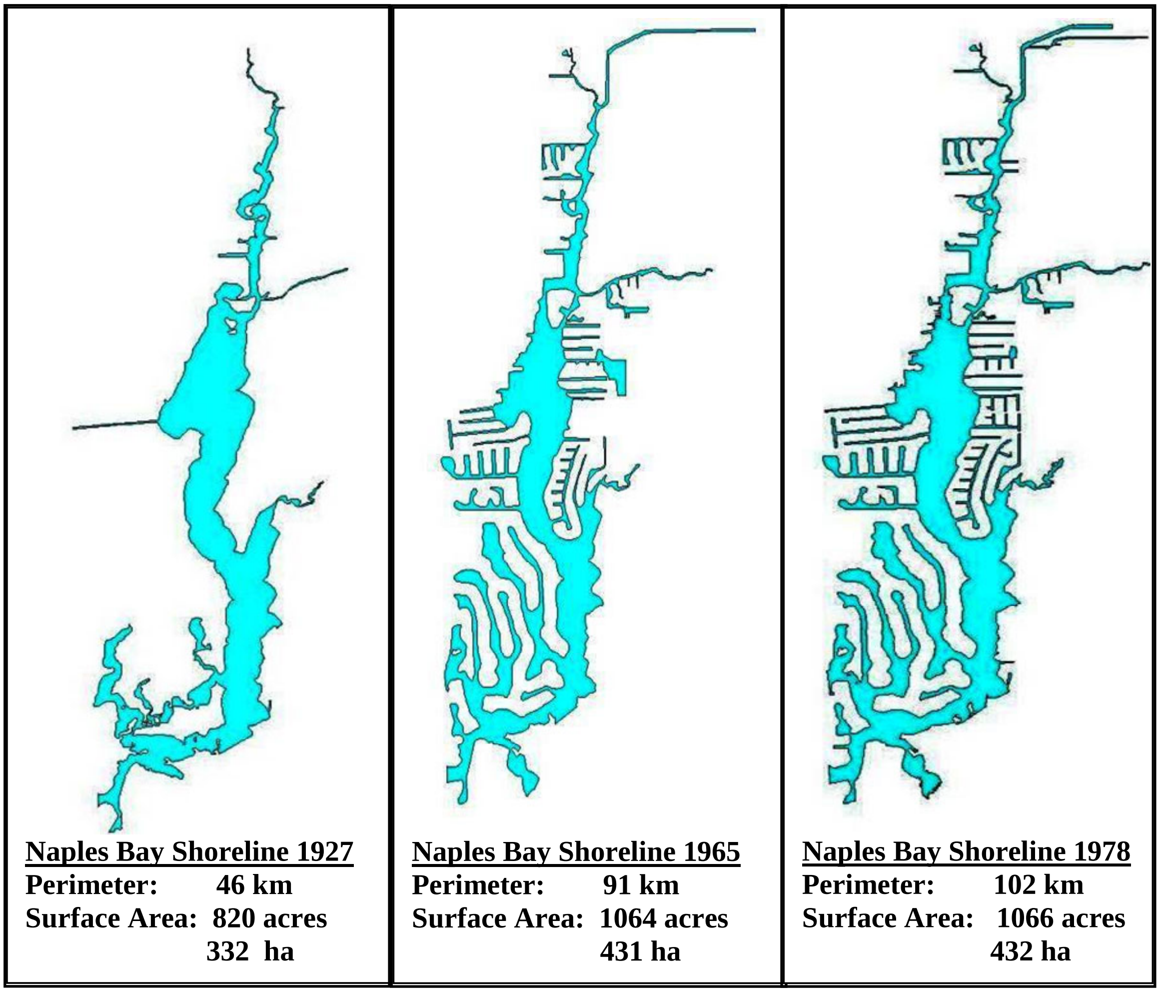


Figure 19. Naples Bay: bathymetry, canals, and other features.



Naples Bay Shoreline 1927
Perimeter: 46 km
Surface Area: 820 acres
332 ha

Naples Bay Shoreline 1965
Perimeter: 91 km
Surface Area: 1064 acres
431 ha

Naples Bay Shoreline 1978
Perimeter: 102 km
Surface Area: 1066 acres
432 ha

Figure 20. The historical shoreline change of Naples Bay (from Schmid and Zimmerman et al., 2006).

Human activities disturbed multiple aspects of the natural system. The alternation of the watershed changed volume, quality, timing, and mixing characteristics of freshwater flows reaching Naples Bay. The increased volume of inflow from the canal and stormwater systems has drastically changed mixing and circulation patterns in Naples Bay and negatively impacted the survival and health of estuarine-dependent species. The construction of waterfront homes removed the vegetation surrounding the bay and replaced it with impervious surfaces (i.e., concrete bulkheads and asphalt roads). **Figure 20** shows that the perimeter of the shoreline was doubled from 1927 to 1965, and was further expanded from 1965 to 1978. Over 70 percent of the fringing mangrove shoreline of Naples Bay has been converted to residential developments. Seagrass and oyster habitats within Naples Bay have been reduced 80 to 90 percent due to dredging for creation of waterfront property and maintenance of navigational channels (Schmid and Zimmerman et al., 2006).

Planned Activities

In 2007, the Surface Water Improvement and Management Plan for Naples Bay was approved by the Governing Board of the South Florida Water Management District. Among the issues identified by the plan are water quantity, water quality, and habitat loss. Implementation of the Naples Bay SWIM Plan is coordinated through the Big Cypress Basin Service Center. The research conducted by the Coastal Ecosystems Division provides the scientific basis for addressing water quality and water quantity issues in Naples Bay. At present, the division is developing a preliminary CH3D hydrodynamic model and a monitoring program to collect the data required for final calibration and verification. Recent and ongoing projects in Naples Bay are outlined in **Table 13**.

Table 13. Recent and ongoing projects in Naples Bay.

Water Body	Study Title	Person of Contact (POC)	Timeline (start and end date)	Data Location	Study Objective	District Strategic Plan Milestone
			Hydrodynamic Modeling			
Naples Bay	Development of Hydrodynamic and Salinity Model in Naples Bay	Chenxia Qiu	Feb-Sept 2007	District	Preliminary CH3D Hydrodynamic Model	Support Naples Bay SWIM Plan
Naples Bay	Salinity and Water Level Monitoring	Chenxia Qiu	Oct 2007-TBD	District	Salinity, water level, flow rate data to support final model calibration and verification	Support Naples Bay SWIM Plan
Naples Bay	Tributary Flow Rates	Big Cypress Basin	Oct 2007-TBD	Big Cypress Basin	Resume discharge monitoring from Golden Gate Canal	Support Naples Bay SWIM Plan
Naples Bay	Naples Bay Hydrologic and Water Quality Data Evaluation	Stormwater Division	May 2005	Repot available from Stormwater Division	Evaluate available data to support hydrodynamic and water quality modeling	Support Naples Bay SWIM Plan
			VEC Assessment			
Naples Bay	Feasibility of Oyster Reef Restoration in Naples Bay: A Reef-Building Demonstration Project	Florida Gulf Coast University	2007	Florida Gulf Coast University	Placement of artificial reefs	Restoration
Naples Bay	Substrate and Subsurface Mapping of Naples Bay using Geophysical Techniques: Implications for Oyster Reef Restoration	Florida Gulf Coast University	2006	Report available from Stormwater Division	Potential placement of artificial reefs	Support Naples Bay SWIM Plan
			Watershed			
Naples Bay	Watershed Management Model	Stormwater Management Division		Ft. Myers	Nutrient Loading Model	Support Naples Bay SWIM Plan

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