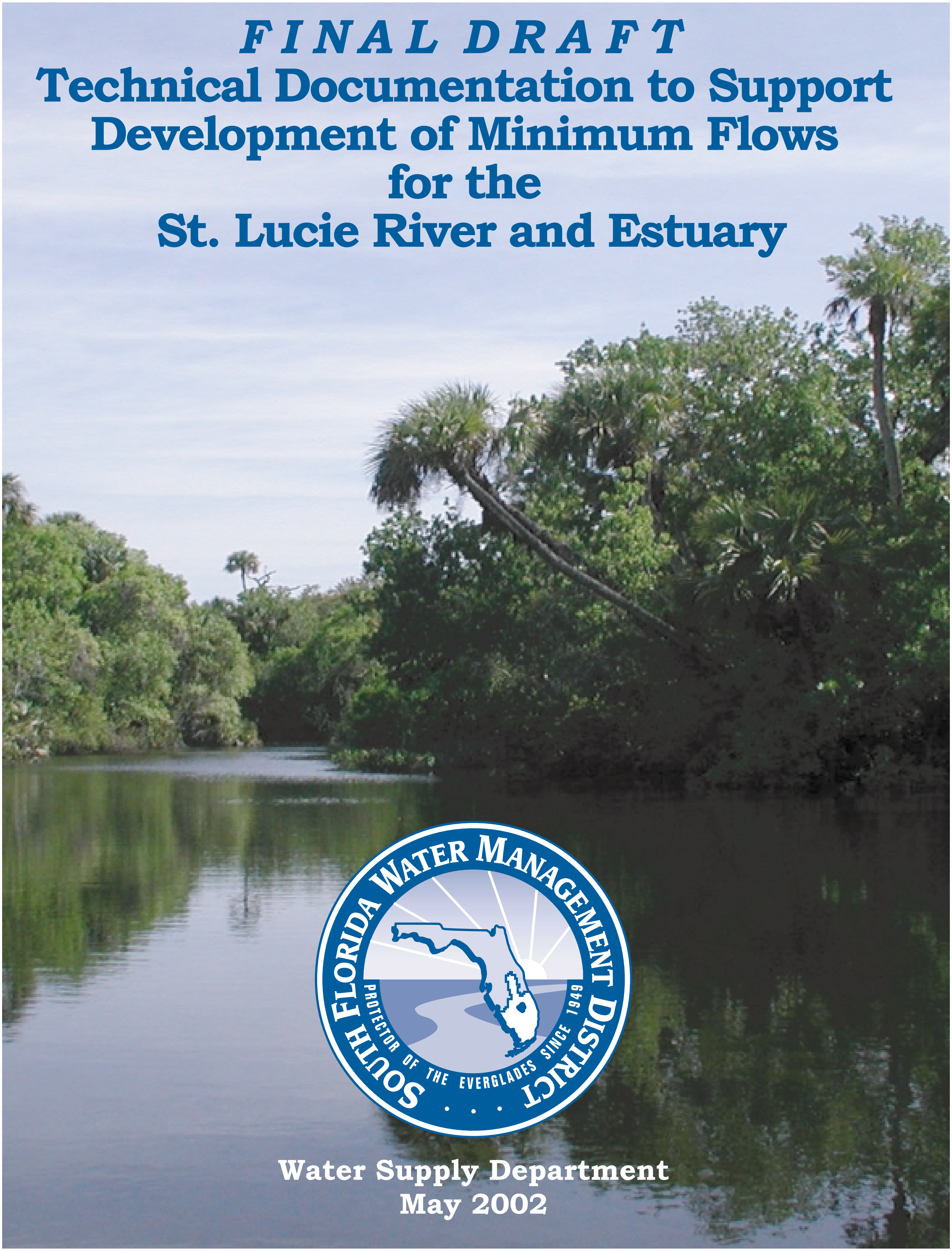
FINAL DRAFT

Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary



Water Supply Department

May 2002

FINAL DRAFT

Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary

Appendices

prepared by the

Water Supply Department
South Florida Water Management District

May 2002

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX A
ST. LUCIE ESTUARY/INDIAN RIVER LAGOON CONCEPTUAL MODEL

Lead Author: Patricia Sime, SFWMD

INTRODUCTION

The St. Lucie Estuary, a major tributary of the Indian River Lagoon, is located on the southeastern coast of Florida. It discharges into the Indian River Lagoon and the Atlantic Ocean through the St. Lucie Inlet. The estuary encompasses approximately 8 square miles (Steward et al., 1994). The 930-square kilometer Indian River Lagoon also receives major discharges from Taylor Creek, the C-25 Canal, Moores Creek, and the Virginia Avenue Canal to the north of the St. Lucie Estuary (Woodward-Clyde, 1994). The Fort Pierce Inlet provides an additional connection between the southern Indian River Lagoon and the ocean. No major Indian River Lagoon tributaries exist from the St. Lucie Inlet south to the Jupiter Inlet.

The model boundary for the St. Lucie Estuary/Indian River Lagoon Conceptual Model extends south to the Indian River Lagoon Surface Water Improvement and Management (SWIM) boundary at the Jupiter Inlet and north to the St. Lucie County line, which is north of the Fort Pierce Inlet. To include the nearshore reef tract, the model extends 3 miles eastward into the Atlantic Ocean. The western boundary includes the open channel headwaters of the North and South Forks of the St. Lucie River and the coastal structures on the C-23, C-24, and C-44 Canals (**Figure A-1**).

Extensive urban and agricultural drainage projects have resulted in hydrologic changes in the watershed of the southern Indian River Lagoon. Approximately 3 inches or 125,000 acre-feet of water storage has been lost. Storm water runoff has increased from 11.2 to 15.7 inches per year and peak runoff rates are higher. Historically, 60 percent of all flows to the St. Lucie Estuary came from the North Fork of the St. Lucie River. Currently, only 25 percent of the runoff flows to the estuary through this historic route. Runoff has increased substantially, from a historic level of 3 percent to 25 percent. Much of this runoff flows through the C-23 Canal, which is an artificial connection into the confluence of the North and South Forks of the St. Lucie River. Along with these hydrologic and land use changes has come a 100 percent increase in phosphorous loading and a 200 percent increase in nitrogen loading.

The drainage projects that have caused these hydrologic changes include the C-23, C-24, C-25, and C-44 Canals, which are part of the Central and Southern Florida (C&SF) Project, as well as smaller secondary and tertiary drainage canals that cross the landscape and direct storm water runoff to the primary canals. Flows that historically made their way slowly through natural wetlands in the C-25 basin to the North Fork of the St. Lucie River now dump directly into the C-25 Canal, which empties into the area of the Indian River

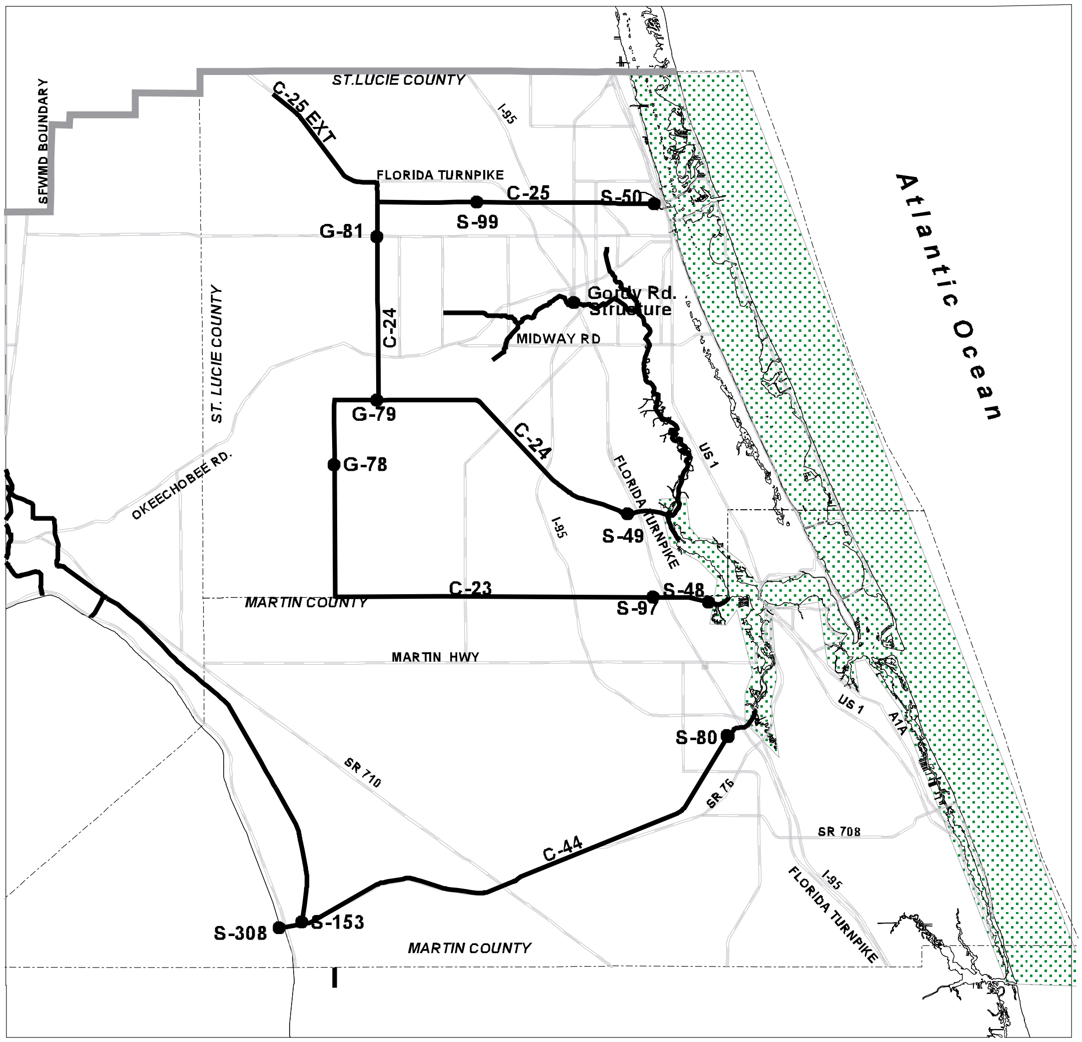


Figure A-1. Indian River Lagoon/St. Lucie Estuary Conceptual Model Boundary

Lagoon around the Fort Pierce Inlet. In addition, the St. Lucie Canal (C-44) provides a link from the St. Lucie Estuary to the lake that did not existed historically. This canal is used to navigate from the St. Lucie Inlet to Lake Okeechobee and to release floodwaters from Lake Okeechobee to tide.

The major effects of anthropogenic changes in the watershed are significant alterations in the timing, distribution, quality, and volume of fresh water entering the estuaries (Steward et al., 1994). Alterations in timing include excess wet season flows and insufficient dry season flows. Despite these impacts, the St. Lucie Estuary and Indian River Lagoon continue to be important resources, with significant environmental and economic values. Understanding how these systems respond to stress will provide a basis for well informed management decisions on restoration activities.

CONCEPTUAL MODEL APPROACH

Participants in a series of interagency workshops, held from August 1999 to November 2000, developed the framework for a conceptual model of the St. Lucie Estuary and the Indian River Lagoon. The conceptual model is structured to support the applied science strategy currently being implemented in the restoration coordination and verification (RECOVER) monitoring and assessment process. The RECOVER monitoring is a major component of the Comprehensive Everglades Restoration Plan (CERP). The St. Lucie Estuary/Indian River Lagoon Conceptual Model identifies the major ecological stressors in the St. Lucie River and Estuary watershed, the ecological and biological effects they have on the ecosystem, and the attributes in the natural systems that are the best indicators of the changes that have occurred as a result of the stressors (USACE and SFWMD, 1999). The basic features of this model are represented in **Figure A-2**. These features are discussed below.

Sources of Ecological Stress

Sources of ecological stress, or external drivers, in the St. Lucie Estuary and the Indian River Lagoon originate from agricultural and urban development and the ensuing construction and operation of water management systems. These sources originate in both local watersheds of the estuary and lagoon and in the larger drainage basins of Lake Okeechobee. Sea level rise is also a factor that affects the ecology of the lagoon system and must be taken into consideration during restoration efforts.

Ecological Stressors

The ecological stressors affecting the St. Lucie Estuary and the Indian River Lagoon are altered hydrology, altered estuarine salinity, input and elevated levels of nutrients and dissolved organic matter, input of contaminants, boating and fishing pressure, and physical alterations to the estuary.

The hydrology and estuarine salinity of the St. Lucie Estuary and the Indian River Lagoon are altered by Lake Okeechobee regulatory releases, basin flood releases, and basin water withdrawals result in altered freshwater flow volume and timing. Water is released from Lake Okeechobee when the lake stage exceeds the stage set in its regulatory schedule, to maintain or enhance environmental conditions in the lake, and to protect agricultural and urban land uses from flooding. Water is withdrawn from Lake Okeechobee during dry periods to fulfill agricultural and urban water demands. Also, sea level rise affects the hydrology and salinity of the St. Lucie Estuary and the Indian River Lagoon.

Agricultural and urban land use practices have resulted in the input and elevated levels of nutrients and dissolved organic matter. Other contaminants, such as pesticides and herbicides, also originate from these practices. These are discharged into the estuary via the canal system and overland flow.

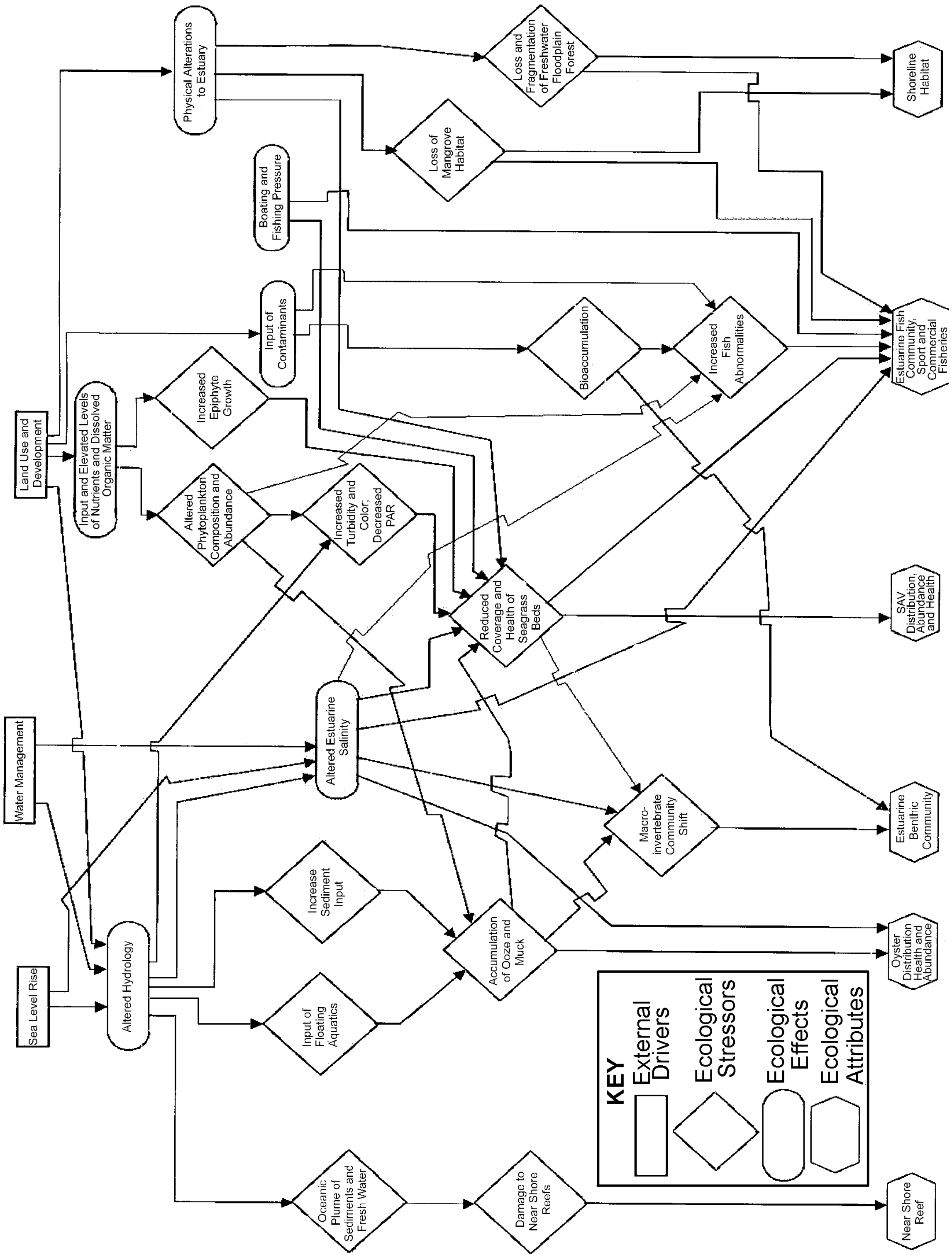


Figure A-2. St. Lucie Estuary/Indian River Lagoon Conceptual Model

Boating and fishing pressure also stress the ecological system. The number of boats utilizing the waterways is rapidly increasing and their support facilities can have adverse impacts on water quality and resources of the lagoon. Fishing pressure began in the 1890s with the development of a commercial industry in the area. With increases in population, the pressure from recreational fisheries may become a larger problem.

Physical alterations to the estuary also impacts the estuary. These alterations are caused by inlet construction and maintenance, and the development of the shoreline and adjacent wetlands of the estuaries and their tributaries.

Ecological Effects of Stressors

Changes in the distribution and timing of water have resulted in both low salinity and hypersalinity events. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish, 1990). The alteration of estuarine salinity zonation has had an overwhelming ecological impact on the St. Lucie Estuary and the Indian River Lagoon.

Regulatory water releases from Lake Okeechobee result in the transport of massive volumes of organic and inorganic sediments. These sediments contribute to the deposits of ooze and muck in the estuaries (Shrader, 1984; Gunter and Hall, 1963; Pitt, 1972). The large accumulations of muck covering the bottom of the estuary dramatically decrease the quality and quantity of habitat for everything from benthic macro invertebrates to oysters and fin fish. High volume releases create an oceanic plume of colored water and suspended solids extending into the Atlantic Ocean out to the nearshore reef.

Together, altered salinity and siltation negatively effect every component of the estuarine and nearshore reef ecosystems, including submerged aquatic vegetation, phytoplankton, fish and macro invertebrate communities, fisheating birds, reef building polychaetes, and the nearshore reef community (Haunert, 1988). The recurring high flow conditions in the St. Lucie Estuary have reduced the numbers of oysters dramatically and the frequency at which these high flows occur have prevented recovery, which takes 3 to 5 years after each prolonged freshet (Cake, 1983). Damage to the nearshore reef habitat, especially the chicken-liver sponges, can produce secondary effects on juvenile green sea turtles that feed on the sponges (Browder, personal communication, 2000). Altered salinity, sudden drops in salinity, or salinity fluctuations are significant stressors to fish and shellfish populations. Lowered salinity and freshwater conditions are conducive to the persistence of fish pathogens, especially fungi, that are found in lesioned fish found in the St. Lucie Estuary (Landsberg, 2000).

The loss and fragmentation of shoreline habitat and the increase in the input of nutrients, dissolved organics, and toxins have exacerbated these problems (Steward et al., 1994). The loss and fragmentation of habitat due to development results in the direct loss of mangrove wetlands and emergent bank vegetation, upon which fish and macro invertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality, contribute to the accumulation of muck, and contribute to changes in phytoplankton communities, macro algae, and submerged aquatic vegetation. Increased input of toxins from agricultural runoff, urban development, and the boating industry, including metals, pesticides and their residues, may lead to bioaccumulation in aquatic food chains leading to fish eating birds. This is one of the factors leading to increased incidence of fish abnormalities in the estuary (Gabriel, 1999). A decrease in the numbers, diversity, and health of fisheries can have secondary effects on the health and mortality of the resident dolphin population in the Indian River Lagoon (Browder, personal communication, 2000).

Ecological Attributes

Nearshore Reef

A nearshore reef forms bands of unique marine habitat 2 to 3 miles offshore of the Atlantic Coast between the St. Lucie and Fort Pierce Inlets. This worm reef, built by *Sabellarid polychaetes*, is very susceptible to silt and salinity variation. The nearshore reef is the northern extent of nonreef building corals. Shallow reef corals reach their northern limit on inshore rock formations adjacent to the St. Lucie Inlet and Jupiter Island, while inshore rock and Sabellarid and algal reefs proceed further north to Cape Canaveral (Zale and Merrifield, 1992; Jaap and Hallock, 1991). Major live coral reefs, *Oculina varicosa,* are only abundant on the shelf edges that occur at depths of 60 to 100 meters.

These complex rock, Sabellarid, and coral structures create benthic fish habitat diversity on the continental shelf resulting in increased biodiversity of lagoon fish in the St. Lucie Inlet (Gilmore, 1995). Approximately 66 percent of the sea grass fishes in the lagoon are species that spawn on the continental shelf (Gilmore, 1988). Also, the nearshore reef is habitat for juvenile green sea turtles.

The continental shelf fish biodiversity is greatly influenced by various reef structures and sediment. The nearshore reef is adversely affected by high level discharges and the resulting silt and salinity plumes that occur mostly to the south of the St. Lucie and Fort Pierce Inlets.

Oyster Distribution Health and Abundance

Oysters and other bivalves, such as mussels and *Rangia,* are sensitive to salinity and siltation in the St. Lucie Estuary and the Indian River Lagoon. Under natural conditions, oyster reefs can be very large and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans, and barnacles (Woodward-Clyde, 1998). Several studies have found over 300 faunal species in oyster beds, including other mollusks, crustaceans, annelids, numerteans, flatworms, sponges, coelenterates, and protozoa (Pearse and Wharton, 1938; Wells, 1961; Bahr and Lanier, 1981).

Historically, oysters were abundant in the estuary and lagoon, covering 1,400 acres. Presently, their distribution is limited to approximately 200 acres. A restoration target of approximately 900 acres of healthy oyster beds has been set. To achieve this, a conducive salinity distribution must be reestablished in areas that provide a potentially suitable bottom habitat. Oysters require soft sediments with little surface structure or roughness. These areas are located using the St. Lucie Estuary Geographic Information System (GIS) Application Model (Woodward-Clyde, 1998).

Work done on oysters in the past documents slightly different preferred ranges and mortality thresholds, these various studies are summarized in the 1998 Woodward-Clyde report. The exact thresholds vary depending on age, condition, temperature, and other factors. Generally adult oysters require salinity levels above 3 parts per thousand (ppt), thrive at 12 to 20 ppt, and are adversely affected by diseases, predators, and algal blooms at seawater salinity conditions. "Dermo", implicated as a cause of 50 percent of adult oyster mortality in Florida, is limited to salinities greater then 9 ppt (Quick and Mackin, 1971; Mackin, 1962).

Estuarine Benthic Communities

Benthic macro invertebrate communities in the St. Lucie Estuary and the Indian River Lagoon are sensitive to bottom type, water quality, and salinity fluctuations. A decline in diversity of benthic organisms and the spread of pollution-tolerant macro invertebrates, such as the polychaete worm (*Glycinde solitaria*), is often one indicator of deteriorated water quality in the estuary and lagoon. Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman, 1985).

Haunert and Startzman (1985) found that an overall reduction of 44 percent of the benthic macro invertebrates occurred during a 3-week experimental freshwater release of 2,500 cubic feet per second (cfs). The greatest change in benthic species composition occurred in the newly created oligohaline zone (0.5 to 5 ppt). In this zone, the freshwater midge (*Chironomus crassicaudatus*) increased dramatically. Additionally, six freshwater species were introduced and at least four estuarine species were lost from the shifted oligohaline zone.

Changes in biodiversity and speciation in the benthic communities brought about by restoration is a hard thing to estimate. It is best illustrated in a study in the Indian River Lagoon by Virnstein (1990). He found that at the meter scale, sea grass beds in the Indian River Lagoon can contain three times the density of macro invertebrates found in unvegetated sediments only a few meters away. At a scale of centimeters, 2 core samples taken next to each other in an apparently homogeneous habitat, often differ in density of macro invertebrates by a factor of 2 or 3.

Salinity Envelop

The estuarine environment is sensitive to freshwater inputs. Modifications to the volume, distribution, circulation, or temporal patterns of freshwater discharges can place severe stress upon the entire ecosystem (Steward et al., 1994). Salinity patterns effect productivity, population distribution, community composition, predator-prey relationships, and food web structure in the inshore marine habitat. Salinity is the master ecological variable that controls important aspects of community structure and food web organization in coastal ecosystems (Myers and Ewel, 1990).

In order to develop an environmentally sensitive plan for the St. Lucie Estuary watershed, biological and physical information was needed to determine a desirable range of flows to the estuary. In 1975, South Florida Water Management District (SFWMD) began baseline investigations to determine the seasonal presence of biota and to document the short-term reactions of estuarine organisms under various salinity conditions during controlled regulatory releases and watershed runoff events (Haunert and Startzman, 1980).

In 1987, the SFWMD research began to support the application of a resource-based management strategy similar to the valued ecosystem component (VEC) approach developed by the United States Environmental Protection Agency (USEPA, 1987) as part of its National Estuary Program. Through this strategy, management objectives are attained by providing a suitable salinity and water quality environment for key species. This approach assumes that environmental conditions suitable for the VEC will also be suitable for other desirable species and that enhancement of the VEC will lead to enhancement of other species.

Utilizing the application of the resource-based management strategy or the VEC approach, a favorable range of inflow and related salinity was established for juvenile marine fish and shellfish, oysters, and submerged aquatic vegetation (Haunert and Konyha, 2001). This favorable range of flows is referred to as the “salinity envelop”. A salinity envelop of 350 to 2,000 cfs was established for the St. Lucie Estuary based on previous research on fish and shellfish, as well as on predicted monthly mean salinity from various inflows at designated areas. A family of curves for salinity in the St. Lucie Estuary was obtained by providing a salinity model with constant inflows until a steady salinity gradient was obtained. Using the family of curves, preferred areas, and preferred salinity for oysters and submerged aquatic vegetation, the salinity envelope can been seen. This provides a method to predict where healthy populations of the VEC would exist if the favorable range of flows and salinity is not violated beyond the frequency that is attributed to natural variation of flows from the watershed. A geographic information system was utilized to define specific locations within the designated VEC distributions. Factors in addition to salinity that were considered for oysters and submerged aquatic vegetation included appropriate depth and type of sediment.

Although the initial salinity envelope defined a range of flows desirable for the VEC and provided useful flow management guidelines, a more detailed understanding of environmentally friendly flows was needed to develop a watershed management plan. The distribution of flows within the range of desirable flows needed to be defined as well as the “acceptable” frequency of violations of desired range. In other words, the full distribution and timing of flows from the watershed that accounts for the natural variation of flows needed to be determined.

Fortunately, recent advances have been made in flow analysis. It is now understood that native aquatic biodiversity depends on maintaining or creating some semblance of natural flow variability and that native species and natural communities will perish if the environment is pushed outside the range of natural variability. Where rivers are concerned, a natural flow paradigm is gaining acceptance. It states “the full range of natural intra- and interannual variation of hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems” (Richter et al., 1997). A similar paradigm is being developed for estuaries. In riverine estuaries, like the St. Lucie, it seems reasonable to evaluate both flows and salinity with respect to their multiple forms of variation. The full range of natural intra- and interannual variation of salinity regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of estuarine ecosystems (Estevez, 2000).

Due to significant improvements in our understanding of St. Lucie Estuary watershed flows, estuary salinity, and the need to go beyond establishing a favorable range of favorable flows, a reassessment of the flow distribution for the St. Lucie Estuary is required to establish a target flow distribution. St. Lucie Estuary watershed flow distribution targets should ensure the protection of the salinity-sensitive biota in the estuary. It is assumed that species diversity in the St. Lucie Estuary requires the hydrology to have characteristics of a natural system and that the monthly flow distribution is a critical hydrologic characteristic. Particularly, the frequency of low monthly flows and high monthly flows should be similar to that of a natural system.

Table A-1 summarizes the flow distribution by range of the three “natural distributions” analyzed and used for comparison to the “current condition.” The current condition is represented by the modeled watershed runoff, which was based on 1995 land use conditions. The Natural Systems Model (NSM) developed for the St. Lucie Estuary watershed and the Hydrologic Simulation Program FORTRAN (HSPF) estimation of predevelopment conditions in the St. Lucie Estuary watershed and Peace River represents the natural watershed conditions in the Peace River Florida watershed. (Haunert and Konyha, 2001).

Submerged Aquatic Vegetation Distribution, Abundance, and Health

The submerged sea grasses and freshwater macrophytes provide habitat and nursery grounds for many fish and invertebrate communities (Gilmore, 1977, 1988; Gilmore et al., 1981, 1983; Stoner, 1983) and they are food sources for trophically and commercially important organisms (Dawes et al., 1995; Virnstein and Cairns, 1986). Other important roles of submerged aquatic vegetation include benthic-based primary productivity and sediment stabilization (Stoner 1983; Virnstein et al., 1983; Gilmore, 1987; Woodward-Clyde, 1998). Sea grass meadows have been described as the marine analog of tropical rain forests because of their structural complexity, biodiversity, and productivity (Simenstad, 1994). In the Indian River Lagoon, sea grasses provide the ecological basis for a fishery industry worth approximately one billion dollars a year (Virnstein and Morris, 1996).

Table A-1. List of Natural and 1995 Base Case Flow-Frequency Distributions Based on 1965-1995 Climate

Flow Range		Probability in Each Range (percent)			
cfs	**acre-feet per meter**	**NSM (target)**	**HSPF**	**Peace River**	**1995 Base Case**
< 350	< 21,130	54.8	47.6	51.9	31.2
350 to 680	21,130 to 41,053	17.7	19.9	20.4	24.2
680 to 1,010	41,053 to 60,976	6.5	9.7	12.6	12.1
1,010 to 1,340	60,976 to 80,898	6.5	5.9	4.3	8.9
1,340 to 1,670	80,898 to 100,821	4.3	4.0	4.6	7.8
1,670 to 2,000	100,821 to 120,744	3.0	4.8	2.2	4.3
2,000 to 3,000	120,744 to 181,116	4.6	5.9	2.4	7.5
> 3,000	> 181,116	2.7	2.2	1.6	4.0
Average Annual Runoff (inches per year)		11.3	14.6	10	16.1

In a field study conducted by Woodward-Clyde in 1997, the only significant submerged aquatic vegetation beds in the St. Lucie Estuary occurred in the lower estuary near Hell Gate Point. Shoal grass *(Halodule wrightii)* was the dominant species throughout most of this area, with Johnson's sea grass (*Halophila johnsonii)* as the secondary species. The only other documented occurrences of submerged aquatic vegetation during that study was a very small amount of widgeon grass *(Ruppia maritima)*, wild celery (*Vallisneria americana)*, and common water nymph (*Najas guadalupensis*) in the South Fork of the estuary as well as a small area of widgeon grass in the North Fork. Additional sea grasses that are important in the Indian River Lagoon include three *Halophila* species (including the federally listed *Halophila johnsonii*), *Syringodium*, and *Thalassia*.

In a sea grass change analysis of the southern Indian River Lagoon, the 47-mile portion of the lagoon was divided into five segments. A preliminary target of the SWIM sea grass program is to restore and maintain sea grasses to a depth of 5.6 feet lagoonwide (Virnstein and Morris, 1996). Between 1992 and 1999, the maximum southern Indian River Lagoon sea grass acreage (9,864) occurred in 1996, representing approximately 50 percent of the target acreage. The lowest acreage mapped during this period occurred in 1999 when sea grass covered approximately 39 percent (7,808 acres) of the target area. To provide a generalized overview of sea grass health and trends for the entire project area, results for the entire southern Indian River Lagoon region are presented in **Tables A-2** and **A-3**. However, trends observed for the southern Indian River Lagoon as a whole do not necessarily reflect sea grass health and trends for individual segments. Accordingly, results for each segment are also presented in the tables and discussed in more detail in *Southern Seagrass Change Analysis (*Robbins and Conrad, 2001).

All species of submerged aquatic vegetation respond negatively to rapidly changing salinity. Decreased light penetration that results from silt, turbidity, color, and phytoplankton blooms further stresses these plant communities. The result has been a decline in the spatial coverage of beds of submerged aquatic vegetation in the estuary and lagoon (Woodward-Clyde, 1998). The St. Lucie Estuary GIS Application Model developed by Woodward-Clyde for the SFWMD in 1998, identifies major areas of the

Table A-2. Southern Indian River Lagoon Sea Grass (1986–1999) and Sea Grass Target Acreage

Lagoon Segment Number	Total Sea Grass Acreage per Mapping Year						Target Acreage
	1986	1989	1992	1994	1996	1999	
1	-	-	365	341	303	320	324
2	-	-	413	281	136	134	870
3	1,806	1,279	1,513	1,571	1,589	1,520	5,469
4	3,916	4,815	4,273	5,007	5,187	2,856	8,833
5	2,471	2,435	2,310	2,307	2,649	2,978	4,303
TOTAL	8,193	8,529	8,874	9,507	9,864	7,808	19,799

Table A-3. Key Sea Grass Change Locations

Segment	Location	1986 - 1989	1989 - 1992	1992 - 1994	1994 - 1996	1996 - 1999
1	Western shore of Hobe Sound	No Data	No Data	Losses along deep edge of sea grass beds	Losses in coves	Minimal change
2	Hole in the Wall	No Data	No Data	Major losses	Minor gains	Minor gains
	Great Pocket	No Data	No Data	Losses along eastern and western shores	Major losses throughout	Minimal change
	Pecks Lake and North Jupiter Narrows	No Data	No Data	Losses in northeastern corner of Pecks Lake	Major loss in North Jupiter Narrows and Pecks Lake	Few sea grasses remain in area
	Northern Hobe Sound	No Data	No Data	Major losses eastern shore	Minimal change	Minimal change
3	Western shore opposite Nettles Island	Major losses	Continued loss	Minimal change	Minimal change	Minimal change
	Eastern shore south of Nettles Island	Gains and losses	Additional losses	Gains and losses	Additional losses	Gains and losses
	Joes Point	Gains and losses	Minor gains and losses	Minor losses	Major gains	Minor losses
4	Eastern shore: Bear Point to Herman Bay	Major gains	Minor gains and losses	North end gains; south end losses	Gains offshore; losses near shore	Major losses (most of "loss" area mapped as algae)
	Western shore	Major loss along deep edge of sea grass beds	Minor gains and losses	Minor gains	Minor losses	Minor losses and gains
5	Western shore: north and south of HBOI	Major gains	Minor losses	Minor losses	Minor gains	Minor gains
	Eastern shore: west of Garfield Cut	Major losses	Minor gains	Minor gains	Minor losses	Minor gains and losses
	Western shore across from Fort Pierce Cut	Major losses	Minor gains	Minor losses	Minor gains and losses	Minor gains and losses

estuary that would be suitable for sea grass establishment were it not for the above impacts. Sea grass loss negatively impacts fish and invertebrate communities. Also, it results in the destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, which provide negative feedback to further diminish sea grass beds (Woodward-Clyde, 1998).

Estuarine Fish Communities/Sport and Commercial Fisheries

The St. Lucie Estuary and Indian River Lagoon provide habitats and nursery grounds for a variety of estuarine fish communities (Gilmore, 1977; Gilmore et al., 1983). Species richness in many of the fish communities of the estuary and lagoon has declined since the 1970s when baseline data were collected. In addition to the general decline in species richness, specific fish communities appear to be affected by salinity and habitat changes.

Submerged aquatic vegetation communities provide nursery ground habitat for juvenile stages of reef and recreationally important fishes in the St. Lucie Estuary and Indian River Lagoon (Lewis, 1984; Virnstein et al., 1983). This community includes mutton, yellowtail and lane snappers, yellowtail parrot fish, gag grouper, sailor's choice grunt, tarpon, snook, jack crevele, spotted sea trout, and redfish. The distribution of juveniles of these species indicates the distribution of stenohaline and stenothermic salinity and temperature conditions in sea grass beds. Sea grass loss and alterations in salinity zonation diminish the habitats suitable as nursery grounds for juvenile reef fish species. Massive freshwater releases from the St. Lucie Canal in the winter of 1998 created significant incidences of fish disease and mortality and toxic dinoflagellate blooms. It also reduced the overall biodiversity of estuarine and freshwater fish communities within the Indian River Lagoon for several months following the release (Gilmore personal data and observations along Bessie Cove, Indian River Lagoon, May 1998, relative to Gilmore 1987; 1988).

The prevalence of diseased and abnormal fish is high in the St. Lucie Estuary. Roughly 15 percent of the fish caught by the National Marine Fisheries Service in the outer estuary and nearshore reef have been visibly abnormal in some way (Browder, personal communication, 2000). The frequency of abnormalities of all types appears to have increased in recent years (Browder et al., 1997; Fournie et al., 1996; Gabriel et al., 1999; Gassman et al., 1994). Although further study, which is currently under way, is needed reach a definitive conclusion, a link between these abnormalities and an increase in the input of toxins, including pesticides and their residues, is suspected to be a major contributing factor.

Ichthyoplankton recruitment into the St. Lucie Estuary and Indian River Lagoon is diminished due to flushing that results from regulatory discharges during key times of the year (Gaines and Bertness, 1992). Estuarine fish species that are negatively affected include the spotted sea trout, snook, the opossum pipefish, and lower trophic level fishes. Snook juvenile settlement rates at specific sites provide a measure of ichthyoplankton recruitment. The spotted sea trout is an estuarine-dependant species that is specifically associated with sea grass beds in the estuary and lagoon. Postlarval and juvenile densities in representative sea grass beds, particularly shoal grass, reflect seasonal salinity and hydrology changes, sea grass bed recovery, and presumably the sports catch of the spotted sea trout.

The opossum pipefish appears to be an indicator of both estuarine and freshwater conditions in the St. Lucie Estuary. Ambient water temperatures and predictable ocean current limit effective breeding of opossum pipefish populations to the Loxahatchee, St. Lucie, and St. Sebastian Rivers of the Indian River Lagoon (Gilmore, 1999). The pipefish is presently a candidate for threatened species listing. Adult opossum pipefish live in freshwater bank vegetation, primarily *Polygonum* and *Panicum* beds. Populations at representative sites appear to be indicators of beneficial wet and dry season salinity conditions. Recruitment of the pipefish in the St. Lucie River occurs during a period of low water flow (through May). Therefore, the November winter release of large volumes of fresh water is atypical and likely to have a deleterious impact on juvenile pipefish movement upstream during this period. (Gilmore, 1999)

Although harvesting of fish and shellfish by the human population of the region has been shown to extend at least 8,000 years back in time to the Ais and Timucuan Indians, the first commercial fisheries did not develop until the 1890s. In a detailed report done by Woodward-Clyde in 1994, it is noted that a shift in species composition of finfish appears to have taken place with a higher proportion of lower priced species being taken more recently. The increased harvest of species such as menhaden and mullet may also have an effect on the overall ecology and productivity of the lagoon. One species, the spotted sea trout, has shown a steady and significant decline (over 50 percent) in landing from 1962 to 1988. This species is almost entirely dependent on the lagoon throughout its life cycle, so its decline may be indicative of adverse conditions within the lagoon. Recreational fishing is continually expanding with the growth of both full-time residents and tourists. The number of fishing trips by residents alone increased from 806,067 in 1970 to 1,811,815 in 1990 and is estimated to increase to 2,890,448 by 2010 (Woodward-Clyde, 1994).

Shoreline Habitat

Mangrove wetlands, forested floodplain, and the emergent bank vegetation of tributaries of the St. Lucie Estuary and Indian River Lagoon support fish and macro invertebrate communities and prevent siltation due to bank erosion. These shoreline habitats have decreased in spatial extent and in function through habitat loss and the loss of connectivity of presently isolated floodplain and shoreline plant communities. A significant portion of the floodplain of the North Fork of the St. Lucie River is completely or partially isolated from the river’s main branch because of dredging conducted during the 1920-1940s. The United States Army Corps of Engineers dredging operations in the North Fork commenced in 1922 and were proceeded by mapping of the watercourse in 1919 (Dames and Moore, 1996). As a result, certain natural communities including floodplain swamp, floodplain forest, hydric hammock, and oxbows (backwater river and stream) from the original watercourse are not fully connected to the existing main branch. A significant portion of the river’s natural filtration of waterborne nutrients is not utilized to its full capacity. Pilot projects are under way to reconnect mangrove and freshwater wetlands in the Indian River Lagoon and channelized upper reaches of the North and South Forks.

PERFORMANCE MEASURES AND TARGETS

In modeling, the effectiveness of a set of alternative management strategies is evaluated using performance measures. Performance measures quantify how well or how poorly a set of alternatives meets a specific target. Good performance measures have the following features: they are quantifiable; they have a specific target; they indicate when that target has been reached; and they measure the degree of improvement toward the target when it has not been reached. The restoration targets that are trying to be achieved in the St. Lucie Estuary and the Indian River Lagoon are discussed below for each attribute.

Nearshore Reef

Target: Reduce siltation rates to natural levels on reefs off the St. Lucie and Fort Pierce Inlets by reducing the silt carried by freshwater plumes that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee

Target: Reduce salinity fluctuations on reefs off the St. Lucie and Fort Pierce Inlets by eliminating the freshwater plumes reaching the reefs that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee

Target: Restore coral, fish, and macro invertebrate community structure and biodiversity of reefs to the conditions documented in baseline data collected in the 1970s

Oysters

Target: Reestablish approximately 900 acres of healthy oysters in the St. Lucie Estuary using the St. Lucie Estuary GIS Application Model to indicate areas most likely to support the reestablishment of oysters

Estuarine Benthic Communities

Target: Increase species richness, abundance, and diversity of benthic species to that typically found in a healthy estuarine community

Salinity Envelope

High Flows

Target: Decrease the numbers of occurrences of flows between 2,000 cfs and 3,000 cfs to less than 4.6 percent of the time

Target: Decrease the number of occurrences of flows greater than 3,000 cfs to less than 2.7 percent of the time

Low Flows

The modeling shows that the current conditions (1995 Base Case) are within the target range for low flow conditions as predicted by the NSM

Target: Keep the number of occurrences of flows less than 350 cfs to less than 54.8 percent of the time

Submerged Aquatic Vegetation

Target: Increase coverage of *Halodule*, *Ruppia*, and *Vallisneria* in the St. Lucie Estuary to include all areas (approximately 920 acres) that are indicated to be suitable habitat based on the St. Lucie Estuary GIS Application Model

Target: Increase coverage of beds of *Halodule*, *Ruppia*, *Syringodium*, *Thalassia*, and the three *Halophila* species, including *H. johnsonii*, in the Indian River Lagoon at depths down to 5.6 feet

Estuarine Fish Communities

Species Richness/Diversity

Target: Increase species richness at benchmark locations, such as Bessey Cove, to levels equaling or exceeding those in the historic (1970s) database and increase species richness above present baseline conditions in other representative sample sites

Incidence of Abnormalities

Target: Decrease the incidence of all types of fish abnormalities to less than one percent in the St. Lucie Estuary and Indian River Lagoon

Juvenile Reef and Recreationally Important Fish

Target: Increase representation of juvenile stages of reef and recreationally important fishes, including the silver snapper species (mutton, yellowtail, and lane), parrot fish, gag grouper, sailor's choice, snook, redfish, and spotted sea trout from present baseline conditions

Lower Trophic Level Fishes

Target: Increase abundance of mullet, menhaden, and anchovy on catch per unit effort to historic (1970s) baseline conditions

Spotted Sea Trout

Target: Increase postlarval and juvenile densities in representative sea grass beds, particularly shoal grass, from present baseline conditions

Snook

Target: Increase juvenile settlement rates of the common and fat snook at representative sites in the St. Lucie Estuary from present baseline conditions

Redfish

Target: Increase abundance of juvenile and adult redfish at representative sites in the St. Lucie Estuary and Indian River Lagoon from baseline conditions

Opossum Pipefish

Target: Increase populations of adult pipefish in *Polygonum* and *Panicum* beds of bank vegetation at representative sites in freshwater tributaries of the St. Lucie Estuary to levels equaling or exceeding those in baseline surveys conducted in the 1970s

Target: Increase seasonal densities of juvenile pipefish in samples in the St. Lucie Estuary

Shoreline Habitat

Target: Increase spatial extent of mangrove and emergent shoreline plant communities through replanting

Target: Reconnect approximately 100,000 linear feet of isolated river floodplain and remove and control exotics on the reconnected floodplain

REFERENCES

Bahr, L.M., and W.P. Lanier. 1981. *The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile*. FWS/OBS-81/15, Office of Biological Services, United States Fish and Wildlife Service, Slidell, LA.

Browder, J.A., and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of freshwater to estuaries. In: Cross, R. (ed), *Proceedings of the National Symposium on Fresh Water Inflow to Estuaries*, September 1980, San Antonio, TX, pp 403-430.

Browder, J.A., N.P. Gassman, M.C. Schmale, and C. Sindermann. 1997. Restoration success criteria based on prevalence of abnormalities in fish. In: *Science Subgroup. Ecological and Precursor Success Criteria for South Florida Ecosystem Restoration*.

Science Subgroup Report to the Working Group of the South Florida Ecosystem Restoration Task Force. Available from the Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL, 33149.

Cake, E.W., Jr. 1983. *Habitat Suitability Index Models: Gulf of Mexico American Oyster*. FWS/OBS-82/10.57, Biological Services Program, United States Fish and Wildlife Service.

Caline, B., Y. Gruet, NEED OTHER AUTHORS. 1992. *The Sabellarid Reefs in the Bay of Mont*. Saint-Michel, France. FOS contributions to Marine Science.

Chamberlain, R., and D. Hayward. 1996. Evaluation of water quality and monitoring in the St. Lucie Estuary, Florida. *Water Resources Bulletin* 32(4):681-695.

Dames and Moore. 1996.

Dawes, C.J., D. Hanisak, and W. J. Kenworthy. 1995. Seagrass biodiversity in the Indian River Lagoon. *Bulletin of Marine Science* 57(1):59-66.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *BioScience* 43(2):86-94.

Estevez, E.D. 2000. *A Review and Application of Literature Concerning Freshwater Flow Management in Riverine Estuaries*. Technical Report Number 680, Mote Marine Laboratory, Sarasota, FL.

Fonsceca, M.S., and J.S. Fisher. 1986. A comparison of canopy friction and sediment movement between four species of sea grass and with reference to their ecology and restoration. *Marine Ecology Progress Series* 29:15-22.

Fournie, J.W., J.K. Summers, and S.B. Weisberg. 1996. Prevalence of gross pathological abnormalities in estuarine fishes. *Trans. Am. Fish. Soc.* 125:581-590.

Gabriel, N.F. 1999. Externally visible fish abnormalities from laboratory and field studies. In: Ranier, R. (ed), *FishBase 99 and FishBase 2000*, CD-ROM. International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines. Also Contribution Number PRD-98/99-11, Southeast Fisheries Science Center, National Marine Fisheries Service, National Ocean and Atmospheric Administration, Miami, FL.

Gabriel et al. 1999.

Gaines, S.D., and M.D. Bertness. 1992. Dispersal of Juveniles and Variable Recruitment in Sessile Marine Species. *Nature* 360:579-580.

Gassman, N.J., L.B. Nye, and M.C. Schmale. 1994. Distribution of abnormal biota and sediment contaminants in Biscayne Bay, Florida. *Bulletin of Marine Science* 54:929-943.

Gilmore, R.G. 1977. Fishes of the Indian River lagoon and adjacent waters. *Florida. Bulletin of the Florida State Museum* 22:101-147.

Gilmore, R.G. 1987. Fish, macrocrustacean, and avian, population dynamics and cohabitation in tidally influenced impounded subtropical wetlands. In: Whitman, W.R., and W.H. Meredith (eds), *Proceedings of a Symposium in Waterfowl and Wetland Management in the Coastal Zone of the Atlantic Flyway*, Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Gilmore, R.G. 1988. *Subtropical Seagrass Fish Communities, Population Dynamics, Species Guilds and Microhabitat Associations in the Indian River Lagoon*. Ph.D. Dissertation, Department of Biological Sciences, Florida Technical, Melbourne, FL.

Gilmore, R.G. 1995. Environmental and biogeographic factors influencing ichthyofaunal diversity: Indian River Lagoon. *Bulletin of Marine Science* 57(1): 155-157.

Gilmore, R.G. 1999. *Life History and Critical Habitat/Environment of Opossum Pipefish: A Population Viability Analysis*. Estuary, Coastal and Ocean Science, Inc., Vero Beach FL.

Gilmore, R.G., and P.A. Hastings. 1983. Observations on the ecology and distribution of certain tropical peripheral fishes in Florida. *Florida Scientist* 46:31-51.

Gilmore, R.G., C.J. Donahoe, D.W. Cooke, and D.J. Herema. 1981. Fishes of the Indian River Lagoon and Adjacent Waters, Florida. Technical Report 41, Harbor Branch Foundation, Harbor Branch Oceanographic Institute, Fort Pierce, FL.

Gilmore, R.G., C.J. Donahoe, and D.W. Cooke. 1983. Observations of the distribution and biology of the east Florida populations of the common snook, *Centropomis undecimalis* (Bloch). *Florida Scientist*, special supplement 45(4).

Gore, R.H., L.E. Scotto, and L.J. Becker. 1978. Community composition, stability and trophic partitioning in decapod crustaceans inhibiting some subtropical sabellariid worm reefs. Bulletin of Marine Sciences 28:221-248.

Gunter, G., and G.E. Hall. 1963. Biological investigations of the St. Lucie Estuary (Florida) in connection with Lake Okeechobee discharges through the St. Lucie Canal. G*ulf Research Reports* 1(5), Ocean Springs, MS.

Haunert, D.E. 1987. *A Proposed Supplemental Water Management Strategy to Enhance Fisheries in the St. Lucie Estuary, Florida*. Unpublished, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E. 1988. *Sedimentation Characteristics and Toxic Substances in the St. Lucie Estuary, Florida*. Technical Publication 88-10, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E., and K. Konyha. 2001. *Establishing St. Lucie Estuary Watershed Inflow Targets to Enhance Mesohaline Biota*, in preparation.

Haunert, D.E., and R.J. Startzman. 1980. *Some Seasonal Fisheries Trends and Effects of a 1000 cfs Freshwater Discharge on the Fishes and Macroinvertebrates in the St. Lucie Estuary, Florida*. Technical Publication 80-3, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E., and R.J. Startzman. 1985. *Some Short Term Effects of a Freshwater Discharge on Biota of the St. Lucie Estuary, Florida*. Publication 85-1, South Florida Water Management District, West Palm Beach, FL.

Jaap, W.C., and P. Hallock. 1991. Coral Reefs In: Myers, R.L., and J.J. Ewel (eds) *Ecosystems of Florida*, Chapter 17, University of Central Florida Press, Orlando, pp 574-616.

Kemp, W.M., R.R. Twilley, J.C. Stevenson, W. Boynton, and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. *Marine Tech. Soc. J.* 17:78-89.

Kennish, M.J. 1990. *Ecology of Estuaries*. Volume 2, CRC Press Boca Raton, FL.

Kirtley, D.W., and W.F. Tanner. 1968. Sabellariid worms: builders of a major reef type. *J. Sediment Petrol.* 38:73-78.

Klump, D.W., J.S. Salita-Espinosa, and M.D. Fortes. 1992. The Role of Epiphytic Periphyton and Macroinvertebrate Grazers in the Trophic Flux of a Tropical Seagrass Community. *Aquatic Biology* 43:327-349.

Lewis, F.G., III. 1984. Distribution of macrobenthic crustaceans associated with *Thalassia, Halodule* and bare sand substrata. *Marine Ecology Progress Series* 19:101-113.

Loosanoff, V.L., and Nomejko. 1951. Existence of Physiologically different races of oysters. *Crassostrea virginica. Biological Bulletin* (Woods Hole) 90(3):244-264.

Mackin, J.G. 1962. Oyster disease caused by *Dermocystidium marinum* and salinity. *Proceedings of the National Shellfisheries Association* 46:116:128.

Mackin, J.G., and S.H. Hopkins. 1962. Studies on Oyster mortality in relation to natural environments and to oils fields in Louisiana. *Publications of the Institute of Marine Science, University of Texas*, 8:132-229.

Morris, L., and D. Tomasko. 1993. *Draft Proceedings and Conclusions for the Submerged Aquaitic Vegetation Initiative and the Photosynthetic Active Radiation Workshops*. Indian River Lagoon National Estuary Program, Melbourne, FL.

Myers, R.L., and J.J. Ewel. 1990. *Ecosystems of Florida*. University Presses of Florida, Gainesville, FL.

Nelson, W.G., K.D. Cairns, and R.W. Virnstein. 1982. Seasonal and spatial patterns of seagrass-associated amphipods of the Indian River Lagoon, Florida. *Bulletin of Marine Science* 32:121-129.

Nielson, S., and B. Eggers, and S. Collins. 2000. The Influence of Seawalls and Revetments on the Presence of Seagrass in the Indian River Lagoon: A preliminary Study. Environmental Management Systems, Inc.

Pearse, A.S., and G.W. Wharton. 1938. The Oyster Leech *Stylocus inimicus* Palombi associated with oysters on the coasts of Florida. *Ecological Monographs* 8:605-655.

Perkins, E.J. 1974. *The Biology of Estuaries and Coastal Waters*. Academic Press, London, United Kingdom.

Pitt, W.A., Jr. 1972. S*ediment Loads in Canals 18, 23 and 24 in Southeastern Florida*. Open File Report 72013, United States Geological Survey, Tallahassee, FL.

Quick, J.A., Jr., and J.G. Mackin. 1971. *Oyster Parasitism by Labyrinthomyxa Marina in Florida*. Professional Paper Series Number 13, Marine Research Laboratory, Florida Department of Natural Resources, St. Petersburg, FL.

Reed, J.K. 1980. Contribution and structure of deep water *Oculina varicosa* coral reefs off central eastern Florida, USA. *Bulletin of Marine Science* 30:667-677.

Reed, J.K. 1981. In situ growth rates of the scleractinian coral *Oculina varicosa* occurring with zooxanthellae on 6-m reefs and without on 80-m banks. *Proc. Int. Coral Reef Cong.*, 4th, Manila 2:201-206.

Reed, J.K. 1985. Deepest distribution of Atlantic hermatypic corals. *Proc. Int. Coral Reef Symp.*, 5th, Tahiti 6:249-254.

Richter, B.D., J.V. Baumgartner, R. Wiginton, and D.P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37:237-249.

Robbins, R., and C. Conrad. 2001. *Southern Indian River Lagoon Seagrass Change Analysis*. In prep.

Sargent, F.J., T.J. Leary, D.W. Crewz, and C.R. Kruer. 1995. *Scarring of Florida's Seagrasses: Assessment and Management Options*. TR-1, Florida Marine Research Institute, Florida Department of Environmental Protection, St. Petersburg, FL.

Shrader, D.C. 1984. *Holocene Sedimentation in a Low Energy Microtidal Estuary, St. Lucie River, Florida*.

Simenstad, C.A. 1994. Faunal association and ecological interactions in seagrass communities of the Pacific Northwest. In: Wyllie-Echeverria, S., A.M. Olsen, and M.J. Hershman (eds), *Seagrass Science and Policy in the Pacific Northwest: Proceedings of a Seminar Series* (SMA 94-1). EPA 910/R-94-004, Seattle, WA, pp. 1-17

Steward, J., R.W. Virnstein, D.E. Haunert, and F. Lund. 1994. *Surface Water Improvement and Management (SWIM) Plan for the Indian River Lagoon, Florida*. St. Johns River Water Management District, Palatka, FL, and South Florida Water Management District, West Palm Beach, FL.

Stoner, A.W. 1983. Distribution of fishes in seagrass meadows: role of macrophyte biomass and species composition. *Fisheries Bulletin* 81(4):837-846.

Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca. 1984. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile*. FWS/OBS-84/02, United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

Tomasko, D.A., C.J. Dawes, M.O. Hall. 1996. The effects of anthropogenic nutrient enrichment on turtle grass (*thalassia testudinum)* in Sarasota Bay, FL. *Estuaries* 19(2B):448-456.

USACE and SFWMD. 1999. *Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental*

Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

USEPA, 1987. *Estuary Program Primer*, Office of Marine and Estuarine Protection, United States Environmental Protection Agency, Washington, D.C.

Virnstein, R.W. 1990. The large spatial and temporal biological variablitiy of the Indian River Lagoon. *Florida Science*. 53(3):249-256.

Virnstein, R.W., and D. Campbell. 1987. Biological Resources. In: Steward, J.S., and J.A. VanAtman, *Indian River Lagoon Joint Reconnaissance Report*, St. Johns River Water Management District, Palatka, FL, and South Florida Water Management District, West Palm Beach, FL, pp. 6-1 to 6-115.

Virnstein, R.W., and K.D. Cairns. 1986. *Seagrass maps of the Indian River Lagoon, Final Report*. Report to the St. Johns River Water Management District, Palatka, FL, submitted by Seagrass Ecosystems Analysts, Inc., Vero Beach, FL.

Virnstein, R.W., and L.J. Morris. 1996. *Seagrass Preservation and Restoration: a Diagnostic Plan for the Indian River Lagoon*. Technical Memorandum 14, St. Johns River Water Management District, Palatka, FL.

Virnstein, R.W., P.S. Mickkelson, K.D. Cairns, and M.A. Capone. 1983. Seagrass beds versus sand bottoms: the trophic importance of their associated benthic invertebrates. *Florida Scientist* 46:363-381.

Virnstein, R.W., W.G. Nelson, F.G. Lewis III, and R.K. Howard. 1984. Latitudinal patterns in seagrass epifauna: Do patterns exist, and can they be explained? *Estuaries* 7:310-330.

Waas, M.L. 1967. Biological and physiological basis of indicator organisms and communities. In: Olsen, T.A., and F.J. Burgess (eds), *Pollution and Marine Ecology*, Interscience, New York, NY.

Wells, H.W. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecological Monographs* 31:239-266.

Wilhm, J.L. 1967. Comparison of some diversity indices applied to populations of benthic macroinvertebrates in a stream receiving organic wastes. *J. Wat. Poll. Cont. Fed.* 39(10):1673-1683.

Wilhm, J.L. 1968. Use of biomass units in Shannon's formula. *Ecology* 49(1):153-156.

Wilhm, J.L. 1970. Range of diversity indices in benthic macroinvertebrate populations. *J. Wat. Poll. Cont. Fed.* 42-5(2): R221-R224.

Wilhm, J.L., and T.C. Dorris. 1968. Biological parameters for water quality criteria. *Bioscience* 18(6):477-481.

Woodward-Clyde. 1994. *Uses of the Indian River Lagoon, Indian River Lagoon National Estuary Program, Melbourne, Florida*. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Woodward-Clyde. 1998. *Distribution of Oysters and Submerged Aquatic Vegetation in the St. Lucie Estuary*. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Zale, A., and S. Merrifield. 1998. *Reef Building Tube Worm*. Department of Zoology, Oklahoma State University, Stillwater, OK.

Zieman, J.C., and R.T. Zieman. 1989. *The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile*. Biological Report 85(7.25), United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

APPENDIX B
OLIGOHALINE ZONE LITERATURE REVIEW REPORT

Lead Author: Rebecca Robbins, SFWMD

INTRODUCTION

The oligohaline, or low salinity, region of an estuary occurs where fresh and saline waters meet. The oligohaline salinity range is typically defined as 0.5 to 5.0 parts per thousand (ppt) (Day et al., 1989), although some studies extend the range to 10 ppt (Coastal Environmental, 1992; Peterson, 1991; Holmes et al., 2000). In contrast to the higher salinity portions of estuaries, relatively few studies have focused on the oligohaline zone (Hackney and de la Cruz, 1981; Hastings et al., 1987; Rozas and Odum, 1987; Odum, 1988; LaSalle and Bishop, 1990; Wagner and Austin, 1999; Holmes et al., 2000; Hughes et al., 2000). No studies are known that detail the functions of the oligohaline zone(s) of the St. Lucie Estuary. However, several studies have identified fish species that occur in low salinity portions of the estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985).

The purpose of this report is to summarize available literature regarding the importance of oligohaline zones in estuaries to assist with development of minimum flows and levels criteria for the St. Lucie Estuary. The studies reviewed generally characterize the oligohaline zone as a physically demanding, dynamic, and highly productive area. These studies suggest processes that occur in this zone are important to overall estuarine ecosystem health. This report summarizes 1) some important physical, chemical, and biological processes that occur in the oligohaline zone; 2) the role of the oligohaline zone as a buffer to downstream waters; and 3) the habitat/nursery value of the oligohaline zone.

PHYSICAL, CHEMICAL, AND BIOLOGICAL PROCESSES

Freshwater inflow to estuaries determines the size and position of the oligohaline zone. Because estuarine inflows are typically variable, the size and position of the oligohaline are variable. The physically dynamic nature of the oligohaline zone, dramatic ionic changes that occur at very low salinities (probably between 1 and 2 ppt) (Deaton and Greenberg, 1986), and high turbidity often associated with this region (Sin et al., 1999) make it a difficult place for organisms to live. Few species have adapted to low salinity environments (Remane and Schlieper, 1971). However, those species able to survive these harsh conditions have the advantage of reduced competition, few predators/disease, and abundant food supply (Rozas and Hackney, 1983; Browder, 1991). These factors may be what attracts some organisms to the oligohaline zone, rather than a specific salinity range (Rozas and Hackney, 1984; Livingston, 1997).

The abundant food supply associated with oligohaline zones is largely due to the nutrients associated with freshwater inflow. These nutrients support phytoplankton growth that can form the base of an extensive estuarine food chain (Hughes et al., 2000). In order for the nutrients to be available for phytoplankton growth within the oligohaline zone, appropriate freshwater discharge rates are needed. Since freshwater discharge rates affect residence time, nutrient input, light regime, and tidal mixing, they can regulate the magnitude, location, and timing of primary production in an estuary (Sin et al., 1999). If discharge is too high the nutrients and/or phytoplankton may be flushed downstream (Holmes et al., 2000) and organisms that depend on this food source may have to leave the "refuge" (few predators, less competition) of the oligohaline zone to take advantage of other food supplies. This could affect community structure throughout the estuary and its receiving waters.

Additionally, important transformations of nutrients occur in the upper estuary (Alpine and Cloern, 1992; Holmes et al., 2000). The processing of nutrients in the oligohaline zone is an important function that can influence energy transported throughout the estuary. Holmes et al. (2000) and Hughes et al. (2000) found that all watershed-derived dissolved inorganic nitrogen was rapidly processed in the oligohaline zone during low flow conditions in the Parker River Estuary in Massachusetts. They indicated that this highlights the importance of the oligohaline zone to the nitrogen cycle of the entire estuary.

Anderson (1986), studying three subestuaries of the Chesapeake Bay, found that freshwater diatoms depleted dissolved reactive silica, a critical nutrient for diatom growth, in the water column before the freshwater flow reached the oligohaline zone. Despite this depletion, he found that dissolved reactive silica levels increased in the oligohaline zone. He suggested that this increase may be a result of the lysing of diatom cells in response to the rapid salinity change in the oligohaline zone. Anderson suggests that this process accelerates remineralization of silica (and probably nitrogen and phosphorus) into the estuary and points to the importance of the oligohaline zone in the cycling of silica.

BUFFER

The processing of nutrients, discussed above, as well as other chemical, physical, and biological transformations in the oligohaline zone (Morris et al., 1978) affect the material and energy transported downstream to the estuary and, ultimately, the ocean. Therefore, Holmes et al. (2000) suggest that the oligohaline zone can be considered an important "buffer or ecotone" between the watershed and the lower estuary and the ocean. Odum et al. (1984) suggested that because of its intermediate position between coastal waters and fresh waters, pollutants (heavy metals, nutrients, suspended solids, etc.) from upstream may be partially intercepted and processed in low salinity areas. In this regard, the oligohaline zone may act as a filter effectively improving the health of downstream habitats.

HABITAT VALUE

Most of the studies reviewed focused on the habitat value of the oligohaline zone. It is apparent that low salinity waters in the upper estuary are critical to the life histories of many estuarine organisms (Holmes et al., 2000; Hughes et al., 2000). A summary of the habitat and/or nursery functions of the oligohaline zone for a wide variety of organisms is presented below.

Micro Invertebrates

As discussed above, the freshwater inflow brings with it nutrients that are used by phytoplankton. The phytoplankton then becomes food for zooplankton such as copepods. In an oligohaline study conducted by Hughes et al. (2000), the most important oligohaline planktonic primary consumer was the copepod, *Eurytemora affinis*, which is found ubiquitously in low salinity waters of North America. This particular copepod appears to mature in the oligohaline zone; consuming diatoms and detritus. Holmes et al. (2000) suspect that a similar trophic structure occurs in the oligohaline zone of other estuaries that support phytoplankton blooms.

Macro Invertebrates

The oligohaline zone provides habitat for numerous macro invertebrates. Boesch and Diaz (1974) found that peracarids (amphipods, isopods, etc.) were more diverse than most other invertebrate groups in oligohaline environments and were probably ecologically important in this zone. Dauvin et al. (2000) reported decapods and peracarids dominate the water column near the bottom of the English Channel forming a direct link between the benthos and the pelagos because of daily vertical and horizontal migrations. In the Seine Estuary, Dauvin et al. (2000) found that biomass of suprabenthic hauls were very high, especially in the mesohaline and oligohaline zones where mysids were abundant.

Other studies focused on the use of the oligohaline zone by barnacles and mollusks. Poirrier and Partridge (1979) studied an oligohaline barnacle, *Balanus subalbidus*, which is reported from estuaries on the East Coast of the United States (including Florida). It is an apparent indicator species of low salinity environments because densities of this organism quickly drop off at salinities above 6 ppt. Another study pointed to the abundance of gastropods and bivalves in poorly flooded oligohaline marshes (Bishop and Hackney, 1987). One specific bivalve, *Rangia cuneata*, grew to greatest size in very low salinity habitats (Gunter, 1961).

Larval Insects

Oligohaline marshes support abundant populations of larval insects, particularly dipteran species (Menzie, 1980; LaSalle and Bishop, 1987, 1990). LaSalle and Bishop (1987, 1990) suggest that low salinity marsh habitats support a larger number of larval insect species than higher salinity areas. Diptera in oligohaline marshes consume oligochaetes, nematodes, and polychaetes, which primarily feed on the microbial-detritus complex (LaSalle and Bishop, 1987, 1990). The larval insects are in turn consumed by aquatic predators such as fish. Additionally, when the insects emerge from their aquatic habitat as adults, they provide an important pathway of energy (biomass) flow into terrestrial ecosystems. Larval insect fauna in oligohaline zones may contribute importantly to the trophic dynamics of estuarine systems (Menzie, 1980).

Fisheries

Most of the habitat studies reviewed focused on the use of the oligohaline zone by fish. Many of the species of fish inhabiting the oligohaline zone support economically important commercial and sport fisheries (Rozas and Hackney, 1983; Day et al., 1989; Edwards, 1992). **Table B-1** provides a list of fish species identified through this literature review that use the oligohaline zone for some part of their life history. The oligohaline zone supports freshwater, estuarine, and marine fishes (Rozas and Hackney, 1983; Odum et al., 1988; Peterson and Ross, 1991). However, marine and estuarine species numerically dominate the oligohaline fauna (Gunter, 1956).

Although the vast majority of fish found in the oligohaline zone are juveniles, several studies pointed to the use of the oligohaline zone by adult fish for spawning and feeding. Striped bass (*Morone saxatilis*), an important commercial and sport fish, is known to spawn and feed in oligohaline and fresh waters (Rozas and Hackney, 1983; Odum et al., 1984). Freshwater species observed spawning in oligohaline waters include bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) (Rozas and Hackney, 1983). Only a few fish are known to be true residents of the oligohaline zone (mosquito fish, *Gambusia affinis*; tidewater silversides, *Menidia beryllina*; and grass shrimp, *Palaemonetes pugio*) (Rozas and Hackney, 1984). In addition to finfish, blue crabs (*Calinectes sapidus*), especially adult males, are known to feed in oligohaline waters (Rozas and Hackney, 1983).

The vast majority of the oligohaline fisheries literature focused on the use of this zone as a nursery (Gunter, 1961; Weinstein, 1979; Day et al., 1981; Rogers et al., 1984; Rozas and Hackney, 1983, 1984; Deegan and Thompson, 1985; Ross and Epperly, 1985; Felley, 1987; Browder, 1991; Peterson and Ross, 1991; Coastal Environmental, 1992; Deegan and Garritt, 1997; Wagner and Austin, 1999). In general, smaller and younger fish initially distribute themselves in lower salinity water and migrate towards the sea as they grow larger (Gunter, 1961). At least some juvenile fish have lengthy stays in the oligohaline zone. Deegan and Garritt (1997) found that some fish stay in the oligohaline zone from the spring through the summer. Weinstien (1979) found that some species remain in the oligohaline zone from winter through fall. For at least one species, the Atlantic menhaden (*Brevoortia tyranus*), the oligohaline zone may be essential for development into juveniles (Rozas and Hackney, 1984).

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Achirus lineatus[a]	Lined sole			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Adinia xenica	Diamond killifish			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Albula vulpes[a]	Bonefish		✔		St. Lucie River, Florida	Haunert and Startzman, 1985
Alosa aestivalis	Blueback herring			✔	North Carolina	Rozas and Hackney, 1984
Alosa alabamae	Alabama shad			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Alosa chysochloris	Skipjack herring			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Alosa pseudoharengus	Alewife		✔		Parker River Estuary, Massachusetts	Hughes et al., 2000
Amia calva	Bowfin			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Anguilla rostrata	American eel			✔	Lake Maurepas, Louisiana Parker River Estuary, Massachusetts	Hastings et al., 1987 Hughes et al., 2000
Anchoa mitchilli[a]	Bay Anchovy	✔	✔		Not specified St. Lucie River, Florida York River, Virginia Barataria Basin, Louisiana St. Louis Bay, Missouri North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana Old Fort Bayou, Missouri Little Manatee River, Florida	Gunter, 1961 Gunter and Hall, 1963 Markle, 1976 Day et al., 1981 Hackney and de la Cruz, 1981 Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991 Edwards, 1992
Apeltes quadracus	Four-spined stickleback			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Aphredoderus sayanus	Pirate perch			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Aplodinotus grunniens	Freshwater drum			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Archosargus probatocephalus[a]	Sheepshead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Arius felis[a]	Hardhead catfish			✔	Lake Maurepas, Louisiana Little Manatee River, Florida	Hastings et al., 1987 Edwards, 1992
Astroscopus sp.	Stargazer			✔	North Carolina	Rozas and Hackney, 1984
Bagre marinus[a]	Gafftopsail catfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Bairdiella chrysoura[a]	Silver perch			✔	York River, Virginia North Carolina	Markle, 1976 Rozas and Hackney, 1984
Brevoortia patronus	Gulf menhaden		✔		Grand and White Lakes, Louisiana Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana Old Fort Bayou, Missouri	Gunter, 1961 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991
Brevoortia smithii[a]	Fine-scale menhaden		✔		St. Lucie River, Florida	Gunter and Hall, 1963
Brevoortia tyrannus[a]	Atlantic menhaden		✔		North Carolina	Rozas and Hackney, 1984

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Callenectes sapidus[a]	Blue crab	✔	✔		Grand and White Lakes, Louisiana Barataria Basin, Louisiana St. Louis Bay, Missouri	Gunter, 1961 Day et al., 1981 Hackney and de la Cruz, 1981
Caranx hippos[a]	Crevalle jack			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Carpoides carpio	River carpsucker			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Catostomus commersoni	White sucker		✔		Parker River Estuary, Massachusetts	Hughes et al., 2000
Centropomus undecimalis[a]	Snook		✔		St. Lucie River, Florida Indian River Lagoon, Florida Little Manatee River, Florida	Gunter and Hall, 1963 Haunert and Startzman, 1980, 1985 Peterson and Gilmore, 1991 Edwards, 1992
Citharichthys spilopterus[a]	Bay whiff			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Crangon septemspinosa	Sand shrimp			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Cynoscion arenarius	Sand seatrout			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Cynoscion nebulosus[a]	Spotted seatrout		✔	✔	St. Louis Bay, Missouri Little Manatee River, Florida	Hackney and de la Cruz, 1981 Edwards, 1992
Cynoscion regalis[a]	Weakfish			✔	York River, Virginia	Markle, 1976
Cyprinodon variegatus[a]	Sheepshead minnow			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Cyprinus carpio	Common carp			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Dasyatis sabina[a]	Atlantic stingray			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Diapterus olisthostomus[a]	Sand perch			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Diapterus plumieri[a]	Striped mojarra			✔	Little Manatee River, Florida	Edwards, 1992
Dormitor maculatus	Fat Sleeper			✔	North Carolina	Rozas and Hackney, 1984
Dorosoma cepedianum[a]	Gizzard shad			✔	North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana	Rozas and Hackney, 1984; Haunert and Startzman, 1985 Hastings et al., 1987
Dorosoma petenense[a]	Threadfin shad			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Elassoma zonatum	Banded pygmy sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Eleotris pisonis	Spinycheek Sleeper			✔	North Carolina	Rozas and Hackney, 1984
Elops saurus[a]	Ladyfish		✔	✔	James River, Virginia St. Lucie River, Florida Lake Maurepas, Louisiana	Govoni and Merriner, 1978 Haunert and Startzman, 1985 Hastings et al., 1987
Enneacanthus gloriosus[a]	Bluespotted sunfish			✔	Atlantic Coast	Rozas and Hackney, 1983 citing Raney and Massmann, 1953
Esox niger	Chain pickerel			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Euciniostomus juveniles[a]	Mojarra		✔		Little Manatee River, Florida	Edwards, 1992

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Eucinostomus argenteus[a]	Spotfin mojarra			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Eucinostomus lefroyi	Mottled mojarra			✔	North Carolina	Rozas and Hackney, 1984
Evorthodus lyricus[a]	Lyre goby			✔	St. Louis Bay, Missouri North Carolina	Hackney and de la Cruz, 1981 Rozas and Hackney, 1984
Fundulus chrysotus	Golden topminnow			✔	Gulf Coast Lake Maurepas, Louisiana	Hastings et al., 1987
Fundulus confluentus[a]	Marsh killifish			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Fundulus diaphanus	Banded killifish			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Fundulus grandis[a]	Gulf killifish			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Hastings et al., 1987
Fundulus heteroclitus	Mummichog			✔	North Carolina Plum Island Sound, Massachusetts Parker River Estuary, Massachusetts.	Rozas and Hackney, 1984 Deegan and Garritt, 1997 Hughes et al., 2000
Fundulus jenkinsi	Saltmarsh topminnow			✔	Old Fort Bayou, Missouri	Peterson and Ross, 1991
Fundulus luciae	Spotfin killifish			✔	North Carolina	Rozas and Hackney, 1984
Fundulus pulvereus	Bayou killifish			✔	Lake Maurepas, Louisiana Old Fort Bayou, Missouri	Hastings et al., 1987 Peterson and Ross, 1991
Fundulus seminolis[a]	Seminole killifish			✔	Little Manatee River, Florida	Edwards, 1992
Galeichthys felis[a]	Sea catfish	✔	✔		St. Lucie River, Florida	Gunter and Hall, 1963
Gambusia affinis[a]	Mosquitofish	✔	✔		St. Lucie River, Florida North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana Little Manatee River, Florida	Gunter and Hall, 1963 Rozas and Hackney, 1984 Haunert and Startzman, 1985 Hastings et al., 1987 Edwards, 1992
Gobionellus boleosoma[a]	Darter goby			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Gobionellus hastatus[a]	Sharptail goby			✔	North Carolina	Rozas and Hackney, 1984
Gobionellus shufeldti	Freshwater goby			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Gobiosoma bosc[a]	Naked goby			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Hastings et al., 1987
Heterandria formosa[a]	Least killifish			✔	St. Lucie River, Florida Lake Maurepas, Louisiana	Gunter and Hall, 1963; Hastings et al., 1987
Ictalurus catus[a]	White catfish	✔	✔		St. Lucie River, Florida York River, Virginia North Carolina St. Lucie River, Florida	Gunter and Hall, 1963 Markle, 1976 Rozas and Hackney, 1984 Haunert and Startzman, 1985
Ictalurus furcatus	Blue catfish			✔	Lake Maurepas Louisiana	Hastings et al., 1987
Ictalurus melas	Black bullhead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Ictalurus natalis	Yellow bullhead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Ictalurus nebulosus[a]	Brown bullhead			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Ictalurus punctatus[a]	Channel catfish			✔	York River, Virginia Lake Maurepas, Louisiana	Markle, 1976 Hastings et al., 1987
Ictiobus bubalus	Smallmouth buffalo			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Labidesthes sicculus	Brook silverside			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lagondon rhomboides[a]	Pinfish			✔	North Carolina Little Manatee River, Florida	Rozas and Hackney, 1984 Edwards, 1992
Leiostomus xanthurus[a]	Spot			✔	York River, Virginia North Carolina Lake Maurepas, Louisiana Little Manatee River, Florida	Markle, 1976 Rozas and Hackney, 1984 Hastings et al., 1987 Edwards, 1992
Lepisosteus oculatus	Spotted gar			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepisosteus ossesus	Longnose gar			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984; Hastings et al., 1987
Lepisosteus spatula	Alligator Gar			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis gibbosus	Pumpkinseed	✔	✔		North Carolina	Rozas and Hackney, 1984
Lepomis gulosus	Warmouth			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis macrochirus[a]	Bluegill	✔	✔		St. Louis Bay, Missouri Lake Maurepas, Louisiana Little Manatee River, Florida Plum Island Sound, Massachusetts.	Hackney and de la Cruz, 1981 Hastings et al., 1987 Edwards, 1992 Deegan and Garritt, 1997
Lepomis meglotis	Longear sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis microlophus[a]	Redear sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis punctatus	Spotted sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis symmetricus	Bantam sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lucania parva[a]	Rainwater killifish			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana Little Manatee River, Florida	Hackney and de la Cruz, 1981 Hastings et al., 1987 Edwards, 1992
Lutjanus griseus[a]	Gray snapper			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Megalops atlanticus[a]	Tarpon		✔		St. Lucie River, Florida	Haunert and Startzman, 1985
Membras martinica[a]	Rough silverside			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Menidia beryllina[a]	Inland or tidewater silverside			✔	North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana Old Fort Bayou, Missouri Little Manatee River, Florida	Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991 Edwards, 1992
Menidia menidia[a]	Atlantic silverside			✔	Plum Island Sound, Massachusetts Parker River Estuary, Massachusetts	Deegan and Garritt, 1997 Hughes et al., 2000
Microgobius gulosus[a]	Clown goby			✔	Lake Maurepas, Louisiana	Hastings et al., 1987

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Micropogonias undulatus[a]	Atlantic croaker		✔	✔	Grand and While Lakes, Louisiana York River, Virginia Upper Barataria Basin, Louisiana North Carolina Lake Maurepas, Louisiana	Gunter, 1961 Markle, 1976 Day et al., 1981 Rozas and Hackney, 1984 Hastings et al., 1987
Micropterus salmoides[a]	Largemouth bass	✔	✔		St. Louis Bay, Missouri North Carolina Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Rozas and Hackney, 1984 Hastings et al., 1987
Morone americana	White perch			✔	York River, Virginia Plum Island Sound, Missouri	Markle, 1976 Deegan and Garritt, 1997
Morone chrysops	White bass			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Morone mississippiensis	Yellow bass			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Morone saxatilis	Striped bass	✔	✔	✔	York River, Virginia North Carolina Lake Maurepas, Louisiana	Markle, 1976 Rozas and Hackney, 1984 Hastings et al., 1987
Mugil cephalus[a]	Striped mullet[a]		✔	✔	St. Lucie River, Florida St. Louis Bay, Missouri North Carolina Lake Maurepas, Louisiana Little Manatee River, Florida	Haunert and Starzman, 1980 Hackney and de la Cruz, 1981 Rozas and Hackney, 1984 Hastings et al., 1987 Edwards, 1992
Mugil curema[a]	Silver mullet[a]		✔		St. Lucie River, Florida	Gunter and Hall, 1963
Myrophis punctatus	Speckled worm eel			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Notemigonus crysoleucas	Golden shiner			✔	St. Lucie River, Florida	Hughes et al., 2000
Notemigonus crysoleucas[a]	Golden shiner			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Notropis emiliae	Pugnose minnow			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Notropis petersonii	Coastal shiner			✔	Old Fort Bayou, Missouri	Peterson and Ross, 1991
Noturus gyrinus	Tadpole madtom			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Oligoplites saurus[a]	Leatherjacket			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Osmerus mordax	Rainbow smelt			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Palaemonetes bulgaris	Grass shrimp			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Palaemonetes pugio	Grass shrimp	✔	✔		St. Louis Bay, Missouri North Carolina	Hackney and de la Cruz, 1981 Rozas and Hackney, 1984
Paralichthys lethostigma	Southern flounder		✔		North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987
Farfantepenaeus aztecus[a]	Brown shrimp		✔	✔	Grand and White Lakes, Louisiana St. Lucie River, Florida Old Fort Bayou, Missouri	Gunter, 1961 Peterson and Ross, 1991

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table B-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference
Farfantepenaeus setiferus	White shrimp		✔	✔	Grand and White Lakes, Louisiana Calcasieu Estuary, Louisiana Old Fort Bayou, Missouri	Gunter, 1961 Gunter and Hall, 1963 Felley, 1987 Peterson and Ross, 1991
Petromyzon marinus	Sea lamprey			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Pleuronectes americanus	Winter flounder			✔	Plum Island Sound, Missouri	Deegan and Garritt, 1997
Poecilia latipinna[a]	Sailfin molley			✔	Little Manatee River, Florida	Edwards, 1992
Pogonias cromis[a]	Black drum			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Polyodon spathula	Paddlefish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Pomatomus saltatrix[a]	Bluefish			✔	North Carolina Plum Island Sound, Missouri	Rozas and Hackney, 1984 Deegan and Garritt, 1997
Pomoxis annularis	White crappie			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Pomoxis nigromacuatus[a]	Black crappie			✔	North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Haunert and Startzman, 1985; Hastings et al., 1987
Pungitius pungitius	Nine-spined stickleback			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Pylodictus olivaris	Flathead catfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Sciaenops ocellatus[a]	Red drum		✔	✔	St. Lucie River, Florida Little Manatee River, Florida	Haunert and Starzman, 1980 Edwards, 1992
Strongylura marina[a]	Atlantic needlefish			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Sygnathus scovelli[a]	Gulf pipefish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Symphurus plagiusa[a]	Blackcheek tonguefish			✔	Gulf and Atlantic Coasts	Rozas and Hackney, 1983 citing Rounsefell, 1964
Syngnathus fuscus	Northern pipefish			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Syngnathus louisianae[a]	Chain pipefish			✔	Gulf Coast	Rozas and Hackney, 1983 citing Dahlberg, 1972
Synodus foetens[a]	Inshore lizardfish			✔	Gulf Coast	Rozas and Hackney, 1983 citing Dahlberg, 1972
Trinectes maculatus[a]	Hogchoker			✔	Grand and White Lakes, Louisiana York River, Virginia Lake Maurepas, Louisiana Little Manatee River, Florida	Gunter, 1961 Markle, 1976 Hastings et al., 1987 Edwards, 1992

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

DISCUSSION

Although studies of the oligohaline zone of estuaries are limited, it is clear that the oligohaline zone is an important estuarine region and that maximizing this zone in an estuary will benefit the estuarine ecology. Physical, chemical, and biological processes in the oligohaline zone are important to estuarine primary productivity and provide a unique habitat and refuge for numerous organisms. The oligohaline zone also acts as a buffer, ecotone, and filter between tidal freshwater areas and downstream estuarine habitats. Additionally, the oligohaline zone provides habitat, including nursery areas, for numerous freshwater, estuarine, and marine organisms.

Although studies specific to the St. Lucie Estuary oligohaline zone(s) have not yet been conducted, it is reasonable to expect that the functions described above for other estuaries would be provided in the oligohaline reaches of this estuary. For example, numerous fish species found in the St. Lucie Estuary (**Table B-1**) are known to occur in oligohaline regions. Restoration and maintenance of a healthy, productive oligohaline zone would benefit these fish species as well as numerous other organisms. Ultimately this should improve sport and commercial fisheries in the area.

Through the minimum flows and levels criteria development process for the St. Lucie Estuary, decisions will be made on the appropriate size and location of the oligohaline zone. The location and size of this zone will be dictated by freshwater inflow. Optimizing the oligohaline zone will require maximizing the overlap of favorable bottom and shoreline features with appropriate salinity ranges (Browder, 1991; Jassby et al., 1995). Maintaining a healthy oligohaline zone will be an important step toward successful restoration and maintenance of the St. Lucie Estuary.

REFERENCES

Alpine, A.E., and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography* 37(5):946-955.

Anderson, G.F. 1986. Silica, diatoms and a freshwater productivity maximum in Atlantic coastal plain estuaries, Chesapeake Bay. *Estuarine, Coastal and Shelf Science* 22:183-197.

Baldwin, A.H., K.L. McKee, and I.A. Mendelssohn. 1996. The influence of vegetation, salinity, and indundation on seed banks of oligohaline coastal marshes. *American Journal of Botany* 83(4):470-479.

Bishop, T.D., and C.T. Hackney. 1987. A comparative study of the mollusc communities of two oligohaline intertidal marshes: Spatial and temporal distribution of abundance and biomass. *Estuaries* 10(2):141-152.

Boesch, D.F., and Diaz R.J. 1974. New records of Peracarid crustaceans from oligohaline waters of the Chesapeake Bay. *Chesapeake Science* 15(1):56-59.

Browder, J.A. 1991. Watershed management and the importance of freshwater flow to estuaries. In: Treat, S.F., and P.A. Clark (eds), *Proceedings, Tampa Bay Scientific Information Symposium 2*, Tampa Bay Regional Planning Council, St. Petersburg, FL, pp. 7-22.

Brown-Peterson, N., and M.S. Peterson. 1990. Comparative life history of female mosquitofish, *Gambusia affinis*, in tidal freshwater and oligohaline habitats. *Environmental Biology of Fishes* 17:33-41.

Bulgar, A.J., B.P. Hayden, M.E. Monaco, D.M. Nelson, and M.G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries* 16(2):311-321.

Chapman, P.M. 1981. Seasonal changes in the depth distributions of interstitial salinities in the Fraser River Estuary, British Columbia. *Estuaries* 4(3):226-228.

Coastal Environmental Services, Inc. 1992. *Oligohaline Areas in Tampa Bay Tributaries: Spatial Extent and Species Lists*. Technical Publication 04-92, prepared for Tampa Bay National Estuary Program, St. Petersburg, FL.

Copeland, B.J. 1966. Effects of decreased river flow on estuarine ecology. *Estuarine Ecology* 38(11):1831-1839.

Dahlberg, M.D. 1972. An ecological study of Georgia coastal fishes. *Fishery Bulletin* 70:323-353.

Dauvin, J.C., C. Vallet, P. Mouny, and S. Zouhiri. 2000. Main characteristics of the boundary layer macrofauna in the English Channel. *Hydrobiologia* 426:139-156.

Day, J.W., Jr., W.H. Conner, G.P. Kemp, and D.G. Chambers. 1981. The relationship of estuarine productivity to wooded swamps and bottomland forests in the southeastern U.S. In: Carey, R.C., P.S. Markovits, and J.B. Kirkwood (eds), *Proceedings U.S. Fish and Wildlife Service Workshop on Coastal Ecosystems of the Southeastern United States*, a compilation of seminars, discussions, papers, and biological summaries presented at Big Pine Key, Florida., February 18-22, 1980. FWS/OBS-80/59, United States Department of the Interior, Washington, D.C., pp 193-213.

Day, J.W., Jr., C.A.S. Hall, W.M. Kemp, and A. Yanez-Arancibia. 1989. *Estuarine Ecology.* Wiley-Interscience, New York, NY.

Deaton, L.E., and M.J. Greenberg. 1986. There is no horohalinicum. *Estuaries* 9(1):20-30.

Deegan, L.A., and R.H. Garritt. 1997. Evidence for spatial variability in estuarine food webs. *Marine Ecology Progress Series* 147:31-47.

Deegan, L.A., and B.A. Thompson. 1985. The ecology of fish communities in the Mississippi River deltaic plain. In: Yanez-Arancibia, A., (ed), *Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration*. UNAM Press, Mexico City, Mexico, pp 35-56

Edwards, R.E. 1992. *Identification, Classification, and Inventory of Critical Nursery Habitats for Commercially and Recreationally Important Fishes in the Manatee River Estuary System of Tampa Bay.* Mote Marine Laboratory Technical Report No. 176, submitted to the Tampa Bay Surface Water Improvement and Management Program, Southwest Florida Water Management District, Fort Myers, FL.

Felley, J.D. 1987. Nekton assemblages of three tributaries to the Calcasieu Estuary, Louisiana. *Estuaries* 10(4):321-329.

Fichez, R., T.D. Jickells, and H.M. Edmunds. 1992. Algal blooms in high turbidity, a result of the conflicting consequences of turbulence on nutrient cycling in a shallow water estuary. *Estuarine, Coastal and Shelf Science* 35:577-592.

Govoni, J.J., and J.V. Merriner. 1978. The occurrence of ladyfish, *Elops saurus*, larvae in low salinity waters and another record for Chesapeake Bay. *Estuaries* 1(3):205-206.

Gunter, G. 1956. Some relations of faunal distributions to salinity in estuarine waters. *Ecology* 37(3):616-619.

Gunter, G. 1957. Predominance of the young among marine fishes found in fresh water. *Copeia* 1:13-16.

Gunter, G. 1961. Some relations of estuarine organisms to salinity. *Limnology and Oceanography* 6:182-190.

Gunter, G., and G.E. Hall. 1963. Biological investigations of the St. Lucie Estuary (Florida) in connection with Lake Okeechobee discharges through the St. Lucie canal. *Gulf Research Reports* 1(5):190-307.

Hackney, C.T., and A.A. de la Cruz. 1981. Some notes on the macrofauna of an oligohaline tidal creek in Mississippi. *Bulletin of Marine Science* 31(3):658-661.

Hastings, R.W., D.A. Turner, and R.G. Thomas. 1987. The fish fauna of Lake Maurepas, an oligohaline part of the Lake Pontchartrain estuary. *Northeast Gulf Science* 9(2):89-98.

Haunert, D.E., and J.R. Startzman. 1980. *Some Seasonal Fisheries Trends and Effects of a 1,000 cfs Fresh Water Discharge on the Fishes and Macroinvertebraes in the St. Lucie Estuary, Florida*. Technical Publication 80-3, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E., and J.R. Startzman. 1985. *Short Term Effects of a Freshwater Discharge on the Biota of St. Lucie Estuary, Florida*. Technical Publication 85-1, South Florida Water Management District, West Palm Beach, FL.

Holmes, R.M., B.J. Peterson, L.A. Deegan, J.E. Hughes, and B. Fry. 2000. Nitrogen biogeochemistry in the oligohaline zone of a New England estuary. *Ecology* 81(2):416-432.

Hughes, J.E., L.A. Deegan, B.J. Peterson, R.M. Holmes, and B. Fry. 2000. Nitrogen flow through the food web in the oligohaline zone of a New England estuary. *Ecology* 81(2):433-452.

Jassby, A.D., W.J. Kimmerer, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecological Applications* 5(1):272-289.

Jordan, R.A., and C.E. Sutton. 1984. Oligohaline benthic invertebrate communities at two Chesapeake Bay power plants. *Estuaries* 7(3):192-212.

LaSalle, M.W., and T.D. Bishop. 1987. Seasonal abundance of aquatic Diptera in two oligohaline tidal marshes in Mississippi. *Estuaries* 10(4):303-315.

LaSalle, M.W., and T.D. Bishop. 1990. Food habits of two larval flies (Dolichopodidae: Diptera) in two Gulf Coast oligohaline tidal marshes. *Estuaries* 13(3):341-348.

Latham, P.J., L.G. Pearlstine, and W.M. Kitchens. 1994. Species association changes across a gradient of freshwater, oligohaline, and mesohaline tidal marshes along the lower Savannah River. *Wetlands* 14(3):174-183.

Livingston, R.J. 1997. Trophic response of estuarine fishes to long-term changes of river runoff. *Bulletin of Marine Science* 60(3):984-1004.

Markle, D.F. 1976. The seasonality of availability and movements of fishes in the channel of the York River, Virginia. *Chesapeake Science* 17:50-55.

Menzie, C.A. 1980. The chironomid (Insecta:Diptera) and other fauna of a *Myriophyllum spicatum* L. plant bed in the lower Hudson River. *Estuaries* 3(1):38-54.

Morris, A.W., R.F.C. Mantoura, A.J. Bale, and R.J.M. Howland. 1978. Very low salinity regions of estuaries: Important sites for chemical and biological reactions. *Nature* 274:678-680.

Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. *Annual Review of Ecology and Systematics* 19:147-176.

Odum, W.E., T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. *The Ecology of Tidal Freshwater Marshes of the United States East Coast: a Community Profile*. FWS/OBS-83/17, United States Fish and Wildlife Service.

Odum, W.E., L.P. Rozas, and C.C. McIvor. 1988. A comparison of fish and invertebrate community composition in tidal freshwater and oligohaline marsh systems. In: Hook, D.D., et al., (eds), *The Ecology and Management of Wetlands, Volume 1: Ecology of Wetlands*, Timber Press, Portland, OR, pp 561-569.

Peterson, M.S. 1988. Comparative physiological ecology of Centrarchids in hyposaline environments. *Canadian Journal of Fisheries and Aquatic Sciences* 45:827-833.

Peterson, M.S. 1991. Differential length-weight relations among centrarchids (Pisces: Centrarchidae) from tidal freshwater and oligohaline wetland habitats. *Wetlands* 11(2):325-332.

Peterson, M.S. 1996. Spatial and temporal changes in subtidal benthic crustaceans along a coastal river-estuarine gradient in Mississippi. *Gulf Research Reports* 9(4):321-326.

Peterson, M., and R.G. Gilmore, Jr. 1991. Eco-physiology of juvenile snook *Centropomus Undecimalis* (Bloch): Life-history implications. *Bulletin of Marine Science* 48(1):46-57.

Peterson, M.S., and S.T. Ross. 1991. Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. *Estuarine, Coastal and Shelf Science* 33:467-483.

Poirrier, M.A., and M.R. Partridge. 1979. The barnacle, *Balanus subalbidus*, as a salinity bioindicator in the oligohaline estuarine zone. *Estuaries* 2(3):204-206.

Rakocinski, C.F., D.M. Baltz, and J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. *Marine Ecology Progress Series* 80:135-148.

Rakocinski, C.F., B.H. Comyns, and M.S. Peterson. 2000. Relating environmental fluctuation and the early growth of estuarine fishes: Ontogenetic standardization. *Transactions of the American Fisheries Society* 129:210-221.

Raney, E.C., and W.H. Massmann. 1953. The fishes of the tidewater secton of the Pamunkey River, Virginia. *Journal of the Washington Academy of Sciences* 43:424-432.

Remane, A., and C. Schlieper. 1971. *Biology of Brackish Water*. John Wiley and Sons, New York, NY.

Rogers, S.G., T.W. Targett, and S.B. van Sant. 1984. Fish-nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Transactions of the American Fisheries Society* 113:595-606.

Ross, S.W., and S.P. Epperly. 1985. Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries. In: Yanez-Arancibia, A., (ed), *Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration*. UNAM Press, Mexico City, Mexico, pp 207-232.

Rounsefell, G.A. 1964. Preconstruction study of the fisheries of the estuarine areas traversed by the Mississippi River - Gulf outlet project. *Fishery Bulletin* 63:373-393.

Rozas, L.P., and C.T. Hackney. 1983. The importance of oligohaline estuarine wetland habitats to fisheries resources. *Wetlands* 3:77-89.

Rozas, L.P., and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. *Estuaries* 7(3):213-224.

Rozas, L.P., and W.E. Odum. 1987. Use of tidal freshwater marshes by fishes and macrofaunal crustaceans along a marsh stream-order gradient. *Estuaries* 10(1):36-43.

Schuchardt, B., and M. Schirmer. 1991. Phytoplankton maxima in the tidal freshwater reaches of two coastal plain estuaries. *Estuarine, Coastal and Shelf Science* 32:187-206.

Schuchardt, B., U. Haesloop, and M. Schirmer. 1993. The tidal freshwater reach of the Weser Estuary: riverine or estuarine? *Netherlands Journal of Aquatic Ecology* 27:215-226.

Sin, Y., R.L. Wetzel, and I.C. Anderson. 1999. Spatial and temporal characteristics of nutrient and phytoplankton dynamics in the York River Estuary, Virginia: Analyses of long-term data. *Estuaries* 22(2A):260-275.

Uncles, R.J., and J.A. Stephens. 1993. The freshwater-saltwater interface and its relationship to the turbidity maximum in the Tamar Estuary, United Kingdom. *Estuaries* 16(1):126-141.

Wagner, M.C., and H.M. Austin. 1999. Correspondence between environmental gradients and summer littoral fish assemblages in low salinity reaches of the Chesapeake Bay, USA. *Marine Ecology Progress Series*, 177:197-212.

Warburton, K. 1978. Community structure, abundance and diversity of fish in a Mexican coastal lagoon system. *Estuarine and Coastal Marine Science* 7:497-519.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. *Fishery Bulletin* 77:339-357.

APPENDIX C
HYDROLOGIC SIMULATION PROGRAM - FORTRAN MODEL FOR THE ST. LUCIE BASIN

Lead Author: Steve Lin

The South Florida Water Management District (SFWMD or District) and the United States Army Corps of Engineers have jointly undertaken a feasibility study which will develop a regional watershed management plan that will improve the quality and temporal distribution of flows to the estuary and lagoon. Hydrologic and hydraulic models of the basin and its canal systems have been developed as part of the study. The Hydrologic Simulation Program FORTRAN (HSPF) was selected for simulating hydrology. The Full Equations (FEQ) Model was chosen for hydraulic routing of the extensive and largely managed canal system under tidal influence conditions and flood conditions where backwater and reversed flow would be a concern.

The existing version of HSPF (version 11) was inadequate for simulating wetlands and high water table conditions found within the St. Lucie River basin. The District contracted Aqua Terra Consultants to implement changes in the hydrology module of HSPF to allow an improved representation of wetlands conditions and dynamic water table variations common to the South Florida region. This modified version of HSPF will become HSPF 12.0.

DESCRIPTION OF THE ST. LUCIE BASIN

The St. Lucie River basin (**Figure C-1**) is located on the southeastern coast of Florida, encompassing 780 square miles. The North and South Forks of the St. Lucie River flow into the St. Lucie River Estuary and through the southern portion of the Indian River Lagoon before discharging to the Atlantic Ocean. The estuary and southern lagoon together form a 30-square mile tidal influenced water body that supports a fragile macrophyte-based estuarine ecosystem.

The watershed can be divided into the following drainage basins based on major drainage features:

- C-23 basin
- C-24 basin
- C-44 basin
- North Fork St. Lucie River basin
- Tidal St. Lucie basin
- Basins 4, 5, and 6
- S-153 basin

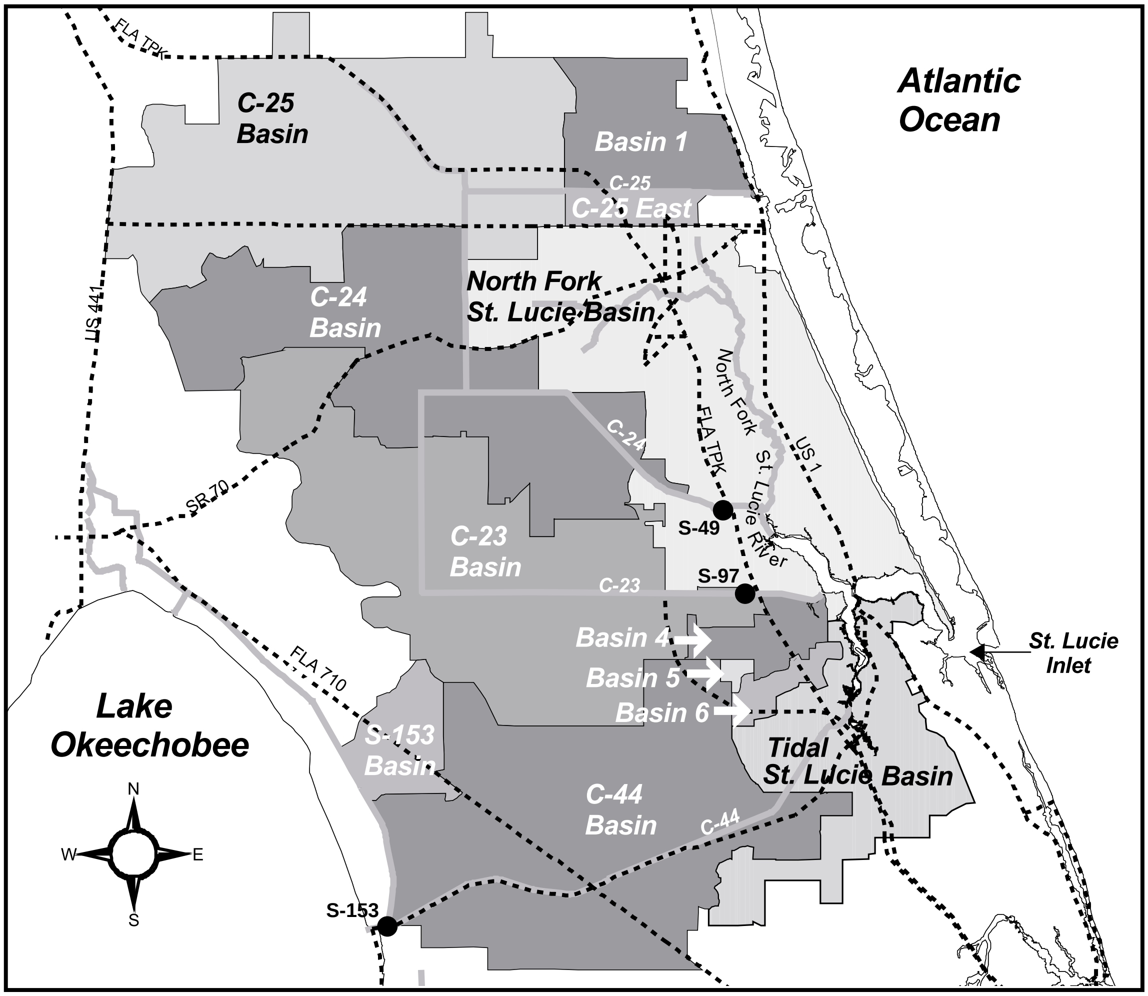


Figure C-1. Primary Drainage Basins in the St. Lucie Estuary Watershed

The topography of the watershed rises gently from sea level on the east to approximately 30 feet National Geodetic Vertical Datum (NGVD) at the coastal ridge. West of the coastal ridge is very low flat land such as Allapattah Flats (elevation of 24 to 30 feet NGVD). Further west, the slope of the land becomes steeper to more than 50 feet NGVD. Areas of depression (wetlands, swamps, etc.) and small ridges occur throughout the watershed.

Soils in the area range from low to high potential seepage rates. The geology of the watershed is dominated by the flatwood soil and soils of sloughs and freshwater marshes, both of which are poorly drained and generally flat.

The climate of the St. Lucie River and Estuary watershed is affected by the subtropical influences of the Atlantic Ocean and Lake Okeechobee. Annual mean temperature is about 73 degree Fahrenheit and average annual rainfall is about 52 inches per year. A wet season occurs from mid-May through mid-October, during which about 62 percent of the rainfall occurs. Tropical storms and hurricanes typically occur during the wet season and contribute a substantial amount of rainfall.

Various land use/land covers exist in the area. Agricultural land use is the dominant land cover in the watershed, with citrus groves and improved and unimproved pasture being the most extensive. Scattered tracts of rangeland, scrub/brushland, and forested uplands occur throughout the area. Forested and nonforested wetlands make up a significant part of the watershed, but much of the historical wetland areas have been converted to agricultural use. Developed residential and commercial centers are concentrated in the eastern part of the area, near the St. Lucie River.

Since the early 1900s canals and water control structures were built to make the region more suitable for agricultural, industrial, and urban development. The original river basin was about 260 square miles but nearly tripled in size after the construction of numerous irrigation and drainage canals. Flood control releases from Lake Okeechobee can also be made through the canals and are often harmful to the estuary. These changes to the landscape and drainage have increased peak discharge rates and volumes during storm events, increased sediment and nutrient loads, and all but eliminated base flows to the estuary during dry periods.

OVERVIEW OF HYDROLOGIC AND HYDRAULIC MODELS

Hydrologic Simulation Program - FORTRAN

The Hydrologic Simulation Program – FORTRAN (HSPF) has been used since 1971 throughout the United States and abroad for all types of land uses. It simulates hydrologic processes including snow accumulation and melt for overland flow under various land use/land covers and water quality processes. Channel processes and reservoirs are also simulated. HSPF is a continuous simulation model. The time scale of simulations varies from 5 minutes to hourly, depending on the process. Statistical analysis of continuous output time series are used to produce data for the economic analysis of alternate water management plans.

The hydrology and hydraulic input requirements of HSPF are precipitation, evaporation, temperature, soil properties, channel properties, land use, topography, supplemental irrigation for crops, etc. The output from the HSPF are time series of flow (e.g., surface runoff, interflow, base flow, deep seepage into a deep ground water system), stages (e.g., ground water tables, water levels in streams and rivers, etc.) All input and output time series are stored in the United State's Army Corps of Engineers' Hydrologic Engineering Center's Data Storage System (HECDSS) files for FEQ model or other result presentations.

The components of watershed water quality models of the HSPF are nonpoint source loading simulations and in stream simulations. Nonpoint source loading simulation includes runoff quantity (surface and subsurface), sediment erosion/solids loading, runoff quality, atmospheric deposition, and input needed by in stream simulation. In stream simulation includes hydraulics, sediment transport, sediment-contaminant interactions, water quality constituents and processes, point source accommodation, reservoir simulation, and benthal processes and impacts.

Full Equations Model

The Full Equations (FEQ) Model is a one-dimensional full equation hydrodynamic flow routing model. The model computes flow and elevation in channel networks for evaluations including the effect of adding, changing, or abandoning a reservoir and the effect of an operation policy for gates or pumps. This model has been applied in Illinois to various types of projects including transportation, county level, and geological survey projects. In the St. Lucie River watershed, the FEQ Model can be used to simulate hydraulics in primary canal and transfers between primary and secondary/tertiary canals. Secondary/tertiary canals are represented as level pool reservoirs. Primary canals are connected to level pool reservoirs by culverts and pumps. Input includes runoff from the HSPF (PERLND Module) and irrigation withdrawals. Output is in the form of time series of flow and stage in primary canals and is stored in HECDSS files.

OVERVIEW OF HSPF ENHANCEMENTS

The following assumptions were used in the standard version of the PWATER section of HSPF (version 11 or earlier):

- No exact storage locations exist for surface detention, interflow, upper/ lower zone, and ground water storage.
- Deep or inactive ground water is not represented.
- The active ground water storage does not interact with the unsaturated zone.
- Both lower and upper zone storage are not affected by the active ground water.
- No percolation flows from the lower zone to active ground water.
- No limited capacity is associated with the interflow storage.
- Surface runoff is driven by the ground surface slope and no evaporation occurs from the surface detention storage.

Many of these assumptions are not valid in South Florida. In the South Florida environment the ground water is very close to the ground surface. The saturated zone interacts with, and even takes over, the unsaturated zone. In many areas the ground water reaches the surface and submerges the land for days or months. The land is so flat that the surface runoff is not driven by differences in ground elevation. Surface water impoundment is subject to evaporation.

All of these invalid assumptions have been enhanced to meet South Florida hydrologic conditions, except the channel/reservoir routing (RCHRES), which is not valid under tidal and backwater conditions. Unsteady flow hydraulic models such as UNET and FEQ can be used in conjunction with the HSPF to route runoff through channel network systems that are subject to tidal, backwater, and reserved flow conditions under extremely wet conditions. Due to considerations of data requirements (such as detail channel cross-sections, field operation data, etc.), computer processor unit storage requirements, and the intensive computer time (time step down to seconds), the linkage of HSPF and a hydraulic model such as FEQ or UNET will only be used when the basin runoff is subject to backwater or tidal flow conditions.

HSPF MODEL OF THE ST. LUCIE BASIN

Segmentation

The St. Lucie basin is divided into six primary drainage basins: C-23, C-24, C-44, the North Fork St. Lucie, and the Tidal St. Lucie, and four minor basins (Basins 4, 5, and 6, and the S-153 basin). These primary drainage basins are further divided into several secondary subbasins. The basin was also divided into eleven precipitation segments using Thiessen polygons centered on rain gages shown in **Figure C-2**. However, due to missing data, concerns of computer storage capacity (31 years of hourly input and output for six land use types and hourly time step), and the available project time line, a simplified approach using average rainfall for each basin was applied and will be presented in detail later.

Land Use

Each subbasin was further segmented by land use, which is one of the most important factors determining hydrologic response. Different treatment and/or characteristics of the soil are reflected in different hydrologic parameters. The 1988 land use conditions from the SFWMD Land Use and Land Cover Geographic Information System (GIS) database were updated to 1994 land use determined by Coastal Environmental, Inc., under contract with the District (Coastal Environmental, Inc., 1994). The following classifications were aggregated into five general categories for HSPF simulation:

- **Urban**: residential, institutional, commercial, industrial, transportation, open, other
- **Groves**: groves, sugarcane, truck farms, rice, ornamental, nurseries, tropical fruits, feedlot
- **Pasture**: improved/unimproved pasture, barren, rangeland
- **Forest**: forest
- **Wetland**: forested and nonforested wetlands

The Urban category is further divided into 60 percent pervious and 40 percent impervious. The impervious urban land is simulated using the IMPLND module of HSPF,

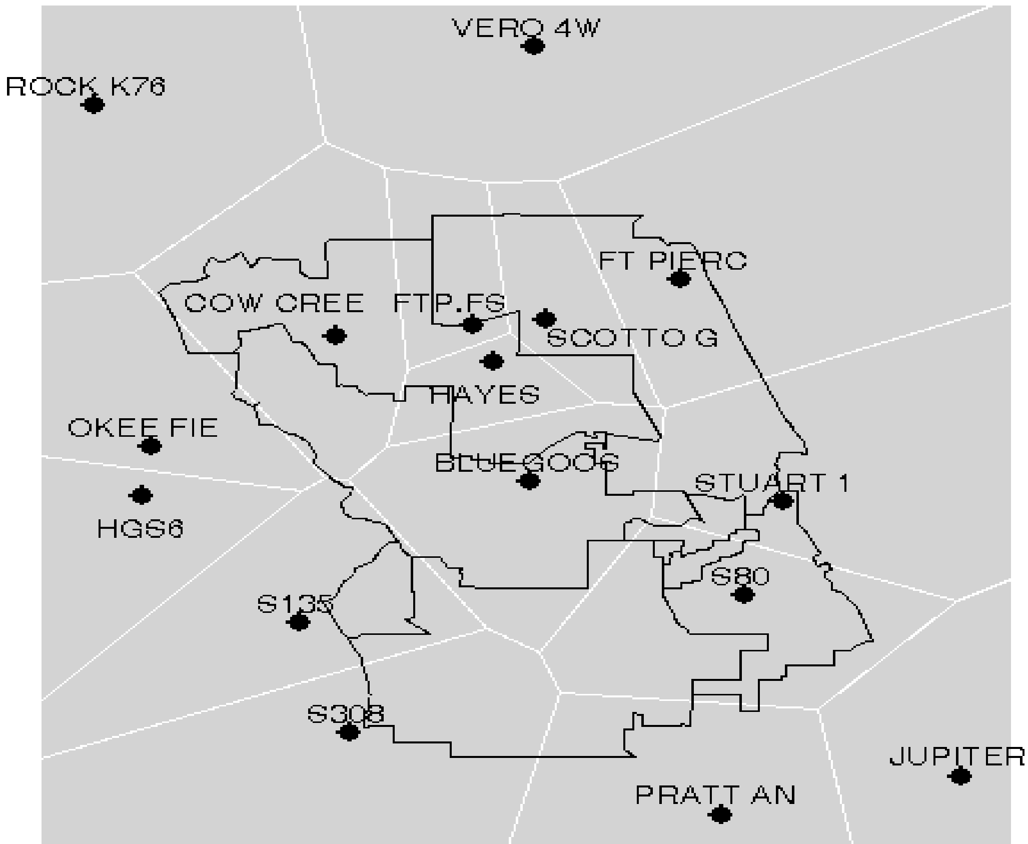


Figure C-2. Thiessen Map of the St. Lucie Estuary Watershed.

while the pervious urban category is simulated using the PERLND module. A complete set of one IMPLND and five PERLNDs is used for each of the eleven precipitation segments. However, as previously mentioned, the precipitation segment was reduced into one segment for each basin to reduce computer storage requirement. **Table C-1** presents the land use by secondary subbasins for each major canal basin.

Table C-1. Land Use by Secondary Subbasin (units in acres)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
C-23 Basin							
1	13	19	5	185	35	10	269
2	48	72	790	840	66	153	1,970
3	167	251	0	0	0	2	420
4	32	47	0	0	0	778	857
5	318	478	0	47	6	191	1,040
6	168	251	0	0	69	176	665
7	121	181	0	0	112	664	1,079
8	48	72	657	9	129	69	985
9	0	0	1,075	25	0	16	1,116
10	9	13	2,728	39	0	322	3,111

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
11	0	0	3,275	0	0	108	3,384
12	0	0	3,007	0	0	40	3,047
15	0	0	0	4,626	40	895	5,562
16	0	0	0	676	0	123	800
17	0	0	0	5,639	45	1,504	7,188
21	0	0	0	1,497	0	173	1,670
22	49	73	120	410	133	16	800
23	0	0	1,309	1,970	2	626	3,906
24	4	6	975	4	0	282	1,270
25	7	10	608	299	0	519	1,442
26	0	0	138	500	0	459	1,097
27	10	15	65	5,746	565	1,017	7,419
28	6	8	225	1,500	423	214	2,376
29	10	15	53	1,241	334	17	2,190
30	0	1	528	292	0	137	959
31	1	1	579	242	30	788	1,641
32	0	0	546	186	33	21	787
33	0	0	0	293	78	70	440
34	0	0	0	474	115	145	734
35	60	90	1,627	628	79	261	2,745
36	0	0	34	255	120	147	556
37	0	0	75	488	533	429	1,526
38	0	0	0	341	0	206	547
39	38	57	138	828	99	222	1,382
40	3	4	1,022	8,429	1,604	1,521	12,582
41	0	0	618	0	0	42	660
42	0	0	1,511	0	0	16	1,526
43	29	43	2,160	233	46	49	2,560
44	0	0	288	0	0	0	288
45	0	0	414	0	0	0	414
46	0	0	291	0	0	0	291
47	0	0	181	0	0	0	181
48	0	0	350	0	0	0	350
49	0	0	1,161	0	0	0	1,161
50	0	0	1,009	0	1	4	1,015
51	0	0	1,265	5	2	379	1,650
52	0	0	4,149	50	55	45	4,298
53	73	109	789	8,216	633	7,099	16,919
C8	40	60	9	0	0	0	345
C9	6	8	0	760	0	888	1,662
C10	0	0	1	155	0	233	389
K5	15	22	298	0	0	0	335
C-23 Basin Total	**1,273**	**1,909**	**34,076**	**47,127**	**5,387**	**21,078**	**111,606**
C-24 Basin							
A	372	559	0	0	42	100	1,073
B	120	180	0	0	1	38	339
C1	47	70	908	917	71	545	2,559

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
C2	2	3	199	654	160	748	1,767
C3	15	22	1,483	3	48	132	1,703
C4	2	3	960	29	1	21	1,015
C5	10	15	294	530	14	92	956
C6	0	0	152	123	2	9	286
C7	20	30	9	457	104	230	849
D	340	510	348	0	1,904	80	3,183
E	0	0	294	2	0	24	320
F	2	3	366	0	0	11	381
G	0	0	610	0	26	333	968
H1	3	5	199	2,650	569	354	3,780
H2	0	0	0	388	207	22	617
I	0	0	259	12	0	20	291
J	0	0	82	191	2	104	379
K1	5	8	1,287	144	33	6	1,484
K2	0	0	6	309	25	0	340
K3	26	38	316	424	130	78	1,011
K4	0	0	7	353	0	23	383
K6	0	0	630	10	0	0	640
K7	1	1	9	429	3	50	494
K8	0	0	96	3	0	0	99
L	115	172	1,948	1,935	184	159	4,512
M	0	0	236	0	0	64	299
N	0	0	310	12	0	0	322
O	0	0	36	1,302	190	106	1,633
P1	0	0	978	1,095	96	43	2,212
P2	0	0	320	0	0	0	320
P3	0	0	8	3,315	3	532	3,858
P4	0	0	955	5	0	4	964
P5	0	0	290	13	0	33	336
P6	0	0	1,025	31	87	146	1,289
P7	0	0	0	614	0	26	641
P8	0	0	641	492	0	741	1,874
P9	0	0	0	661	9	178	848
P10	0	0	609	5	1	34	649
Q	0	0	15	1,253	58	33	1,359
R	0	0	933	4	19	1	958
S	0	0	826	0	6	11	842
T	0	0	268	0	3	4	275
U	89	133	2,126	23,302	2,969	13,455	42,072
V	0	0	282	152	3	0	437
C-24 Basin Total	**1,169**	**1,753**	**20,318**	**41,818**	**6,968**	**18,590**	**90,617**
C-44 Basin							
1	0	0	198	1,584	156	46	1,984
2	0	0	12	1,976	170	1,852	4,010
3	80	120	748	1,004	265	1,248	3,464
4	72	107	3,993	2,628	397	2,085	9,281

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
5	17	25	705	814	23	16	1,600
6	0	0	2,955	0	194	12	3,161
7	0	0	1,586	1,062	95	327	3,071
8	38	57	215	1,512	0	319	2,141
9	0	0	1,886	8	76	0	1,971
10	16	23	656	1,210	393	807	3,104
11	1	2	819	0	60	0	881
12	3	4	1,718	385	0	1,484	3,594
13	0	0	7,808	248	140	726	8,921
14	231	346	6,866	4,875	1,112	998	14,428
15	34	51	0	9	245	2	341
16	303	454	933	918	744	272	3,625
17	12	18	4,781	478	91	3,290	8,670
18	6	9	859	4	24	0	902
19	2	4	3,254	0	279	5	3,545
20	0	0	2,020	0	499	0	2,520
21	74	111	476	84	30	167	940
22	0	0	1,223	196	0	4	1,423
23	100	150	931	0	216	445	1,841
24	267	401	1,828	186	167	2,007	4,856
25	2	3	0	0	0	1,609	1,614
26	16	24	43	216	0	1,384	1,681
27	13	19	23	22	24	742	842
28	0	0	11	0	81	117	210
29	28	42	1,038	0	390	0	1,498
30	395	592	405	51	439	7,377	9,259
31	17	26	881	5,905	1,180	2,708	10,717
C-44 Basin Total	**1,724**	**2,587**	**48,873**	**25,372**	**7,490**	**30,049**	**116,095**
North Fork St. Lucie Basin							
A1	1,399	2,098	0	0	368	2,355	6,220
A2	3,125	4,688	0	0	319	337	8,469
B1	2,015	3,022	1	10	987	3,277	9,312
B2	0	0	0	0	44	0	45
B3	5	8	15	0	26	0	55
C1	1,321	1,981	0	4	42	126	3,474
C2	891	1,336	0	0	1	282	2,509
C3	801	1,201	0	0	0	153	2,155
D1	417	626	9	3	403	278	1,736
D2	387	580	0	0	319	580	1,866
D3	113	170	0	0	7	14	304
D4	8	12	0	0	1	0	20
E1	82	123	144	7	175	228	759
E2	381	571	246	53	303	208	1,761
F1	2,653	3,980	0	0	215	614	7,462
F2	453	680	0	767	1,441	216	3,558
G1	488	733	76	433	710	545	2,984
G2	1,056	1,584	138	357	1,482	473	5,090

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
H1	186	280	55	2	130	92	744
H2	134	201	64	114	92	54	660
I	208	313	44	558	314	344	1,781
J	185	278	291	329	230	459	1,771
K	170	255	0	0	46	43	513
L	176	265	0	13	105	6	565
M	4	6	0	37	10	67	124
N	17	26	12	30	18	78	183
O	25	37	22	6	0	50	139
P	25	38	105	10	63	174	414
Q	38	56	94	21	29	100	338
R	14	21	408	144	15	149	752
S	347	520	1,645	655	1,172	392	4,730
T	26	38	237	67	162	18	548
U	85	127	2,074	411	462	1,336	4,494
V	21	31	6,724	68	13	129	6,984
W1	53	80	580	353	168	1	1,235
W2	60	90	475	489	104	17	1,236
W3	82	123	2,738	128	118	44	3,232
W4	8	12	1,083	11	13	0	1,127
W5	1	1	607	8	0	29	645
W6	4	6	2,059	22	3	5	2,098
W7	0	0	1,836	143	0	109	2,088
W8	1	2	2,255	9	0	148	2,416
W9	0	0	2,086	6	8	0	2,101
X1	254	382	56	0	44	0	736
X2	201	301	0	0	40	0	542
X3	98	146	103	5	55	20	427
X4	197	296	175	12	33	2	715
X5	168	252	226	98	199	9	952
X6	148	222	340	28	255	37	1,031
X7	99	148	193	37	156	5	639
X8	41	62	0	0	0	0	103
X9	245	368	103	0	145	25	887
North Fork St. Lucie Basin Total	**18,916**	**28,373**	**27,317**	**5,448**	**11,047**	**13,630**	**104,731**
Tidal St. Lucie Basin							
1	313	469	0	0	3	1	786
2	398	597	8	15	162	25	1,206
3	233	349	13	0	203	55	854
4	738	1,108	91	76	476	844	3,332
5	68	101	0	0	26	121	316
6	156	234	50	103	22	692	1,256
7	23	35	0	0	0	3	61
8	13	19	0	0	0	0	32
9	34	50	0	0	12	2	98
10	388	582	696	157	271	1,431	3,525

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
11	701	1,051	3,063	11,998	1,548	8,014	26,375
12	404	606	209	486	599	281	2,585
14	170	254	829	594	388	117	2,352
15	34	52	357	765	135	13	1,357
16	0	0	478	32	136	0	646
x17	256	385	615	480	568	453	2,757
Tidal St. Lucie Total	**3,928**	**5,892**	**6,409**	**14,706**	**4,548**	**12,053**	**47,537**
Basin 4							
1	427	641	0	45	73	109	1,296
2	195	0	0	0	9	6	503
3	122	183	0	0	77	98	479
4	160	240	59	81	92	180	812
5	174	261	0	34	52	28	550
6	44	66	0	18	14	11	153
7	66	100	0	5	261	0	431
8	18	27	96	269	90	1	501
9	3	4	0	314	260	1	581
10	1	2	0	81	307	3	395
11	0	0	2	518	236	119	874
12	0	0	21	27	9	0	56
13	50	75	25	0	36	1	188
14	5	8	11	4	21	0	48
15	31	46	0	0	44	0	121
16	6	9	0	2	21	0	38
17	14	21	0	0	68	0	103
18	4	6	0	22	94	0	126
19	7	11	0	18	24	1	61
20	9	13	0	64	39	3	128
21	0	0	0	21	9	1	30
22	17	25	0	50	23	0	115
23	74	111	0	23	53	317	577
24	11	17	5	85	82	6	207
25	2	3	0	6	176	393	580
Basin 4 Total	**1,441**	**1,870**	**220**	**1,687**	**2,165**	**1,278**	**8,953**
Basin 5							
1	27	40	9	9	57	1	144
2	22	33	5	4	4	0	68
3	157	236	6	29	190	129	747
Basin 5 Total	**206**	**309**	**21**	**42**	**251**	**131**	**959**
Basin 6							
1	100	150	21	2	170	2	446
2	127	190	3	172	42	98	632
3	21	31	0	127	1	1	180
4	24	35	0	32	39	5	135
5	4	5	0	61	4	0	74
6	16	24	0	0	47	0	87
7	7	11	32	0	13	0	62

Table C-1. Land Use by Secondary Subbasin (units in acres) (Continued)

Subbasin	Urban Impervious	Urban Pervious	Groves	Pasture	Forest	Wetland	Total
8	28	42	39	26	20	0	155
9	12	17	0	0	31	0	60
10	39	58	44	44	28	0	212
11	120	181	24	145	267	112	849
12	23	35	10	30	25	0	123
13	50	75	0	32	0	0	157
14	79	118	10	11	83	0	301
15	186	278	0	120	115	11	710
16	29	43	0	1	190	394	658
Basin 6 Total	**863**	**1,295**	**183**	**801**	**1,075**	**624**	**4,840**
S-153 Basin							
S-153	447	671	2,069	4,129	1,428	4,175	12,920
S-153 Basin Total	**447**	**671**	**2,069**	**4,129**	**1,428**	**4,175**	**12,920**
Grand Total	**29,968**	**44,659**	**139,486**	**141,131**	**40,359**	**101,607**	**498,258**

Rainfall

Rainfall data was extracted from the District's DBHYDRO database. Data from 11 daily and 6 hourly rainfall stations were used (**Table C-2**). Missing data were filled from adjacent stations. Three of the hourly stations within and near the basin have periods of record from 1965 to 1995. These stations were used to desegregate the daily data for each basin to produce hourly data for use in the HSPF simulations, covering the period from 1965 to 1995.

Accumulated rainfall was determined by applying a weighing factors to the data from each station. **Table C-3** presents rainfall stations and weighing factors used for each basin in the St. Lucie basin.

Evaporation

Daily evaporation data are available at three locations within or near the watershed: Fort Pierce Experimental Station, Belle Glade Experimental Station, and Hurricane Gate Structure 6. The potential evapotranspiration record at Fort Pierce Station is the primarily data used in the model. Missing data in this station were filled using the other two stations. The model uses a pan coefficient to derive an estimate of potential evapotranspiration. Actual (simulated) evapotranspiration is based on three general factors: the model algorithms, the evapotranspiration parameters, and the input potential evapotranspiration. The pan coefficients were determined by applying a model calibration process based on the chemicals, runoff, and erosion from agricultural management system with water table (CREAMS-WT) model to the C-23 and C-24 basins. The pan coefficients chosen were 0.60 for the C-24 basin and 0.64 for the rest of the watershed.

Table C-2. Summary of Rainfall Data for the St. Lucie Basin Simulations

Station Identification Number	Station Name	Period of Record
Daily Rainfall Stations		
NOAA -6032	Fort Pierce	1962-1995
MRF-39	Scotto Groves	1962-1995
MRF-37	Fort Pierce Field Station	1971-1995
MRF-148	Cow Creek Ranch	1971-1995
MRF-40	Hayes Property	1971-1995
MRF-241	Bluegoose	1979-1995
NOAA-6082	Stuart 1N	1957-1995
MRF-7035	S80 (NOAA-7859)	1957-1995
MRF-54	Pratt and Whitney	1957-1995
MRF-7037	S308 (NOAA-7293)	1957-1995
MRF-150	S-153	1972-1995
Hourly Stations		
MRF-40	Hayes Property	1971-1995
MRF-148	Cow Creek Ranch	1970-1995
MRF-241	Bluegoose	1979-1995
MRF-7035	S80 (NOAA-7859)	1965-1994
MRF7037	S308 (NOAA-7293)	1965-1994
NOAA-9219	Vero Beach 4W	1965-1995

Soils, Slopes, and Elevation

The District's GIS database contains land use/cover, soil types, topography, and hydrography. The soil properties database contains hydrologic soil groups, permeability, porosity (maximum/minimum available water capacity), and erosion factors. The data are generally available for two depth horizons (0 to 20 inches and 20 to about 60 inches). However, some secondary basins do not have soil data due to owners' access restriction to their properties. The available data were used to estimate the range and the variability of porosities, infiltration rates, and soil storage parameters in PERLND module.

Land slopes are not generally used in the HSPF 12.0. However, average elevations for each segment were estimated from the United States Geological Survey 7.5-minute quadrant maps. For the Ten Mile Creek basin, topography data from the early 1980s was used. Portions of eastern Martin County were available from the District's GIS database.

Supplemental Irrigation

One of the major environmental concerns in both the St. Lucie Estuary and the Indian River Lagoon is the timing and distribution of freshwater inputs that results from postproject conditions. The present freshwater flow pattern has been characterized as follows:

- Low flows are exaggerated during the dry season months.

Table C-3. Rainfall Stations and Weighing Factors Used for Each Basin

Basin	Rainfall Station	Weighing Factor	Period of Record
C-23	MRF148 MRF40 MRF44 MRF150 MRF7035	0.30 0.25 0.10 0.15 0.20	1972-1978
	MRF148 MRF241 MRF44 MRF150 MRF7035	0.30 0.40 0.10 0.10 0.10	1979-1995
C-24	MRF148 MRF40 MRF37	0.3333 0.3333 0.3333	1971-1978
	MRF148 MRF40 MRF37 MRF241	0.25 0.25 0.25 0.25	1979-1995
C-44	MRF7035 MRF7037 MRF54	0.40 0.40 0.20	1957-1971
	MRF150 MRF7035 MRF7037 MRF54	0.15 0.35 0.35 0.15	1972-1995
North Fork	MRF6032 MRF39 MRF37 MRF6082	0.40 0.25 0.15 0.20	1965-1995
Ten Mile Creek	MRF6032 MRF39	0.50 0.50	1965-1995
S-153	MRF7037	1.00	1965-1970
	MRF150	1.00	1971-1995
Tidal St. Lucie	MRF6082 MRF7035 MRF54	0.20 0.70 0.10	1965-1995

- Reduction or lack of flush from spring rainfall is caused by irrigation for agricultural activities.
- An excess quantity of fresh water is received during the wet season for crop and residential flood protection.
- Drainage capacity is increased compared to preproject conditions.

The canal system primarily serves as a source of agricultural irrigation water and a means to control water table levels to maximize crop production and reduce flood damages. During the wet season, flows to the estuary often increase abruptly and result in much greater volumes of freshwater discharge to the estuary compared to predevelopment conditions. Conversely, during the dry season, fresh water is in short supply and the canal system is controlled to retain and reuse fresh water for irrigation to the maximum extent possible. These activities greatly reduce dry season base flows that normally would enter the estuary under preproject condition.

Site-specific data on irrigation application amounts, acreage, and timing were scarce. The water use permits did not provide sufficient information to be useful in the model simulation. The amounts of irrigation withdrawn from surface water to mix with ground water sources are not easily estimated.

The irrigation method and the acreage irrigated, in general, are available from the *Indian River Lagoon Agricultural Land-Use Inventory and Discharge Study* prepared by the United States Department of Agriculture's Soil Conservation Service in December 1993 (SCS, 1993). The information was compiled by using the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) developed by Smajstrla (1990). The AFSIRS was used to develop 31 years of daily irrigation demands and irrigation supply for the North Fork and C-44 basins. The results were compared, using a calibration process, to the supplemental irrigation derived from the model calibrated results for the C-23 and C-24 basins (see below).

The amounts of irrigation used by the citrus growers are based on the observed daily water levels, the daily flow at water control structures, and channel cross-sections. The daily withdrawal was estimated by the daily stage difference and the stage-area-volume relationship derived from the channel cross-section. This volume of water was then divided by the total irrigated area to come up with irrigation amount in inches per day for 31 years. This amount was than increased by 40 percent (SFWMD, 1998) to cover the additional water withdrawn from deep ground water sources. A time series of total daily irrigation withdrawal (both from surface and deep ground water sources) for 31 years was developed and applied in the HSPF model calibration simulations. These time series were adjusted for additional precipitation for the citrus groves within the basin. This data set was further adjusted based on the calibration of discharge through structures, and water level agreements between computed and observed data at the structure.

HSPF USER CONTROL INPUT FILES

A single user's control input file that simulates the runoff from land area within the St. Lucie River and Estuary watershed was set up for each basin. The user's control input file breaks down the basin primarily by precipitation segment, rather than by secondary basin boundaries. As discussed in the **HSPF Model of the St. Lucie Basin** section on **page 5**), each of the eleven precipitation segments has six land use categories represented by five PERLND operations plus one IMPLND operation. These operations produce per acre water yield (runoff) for each land segment. The outflows are multiplied by the corresponding acreage in the SECHEMATIC block and accumulated by the COPY operations to give the total runoff for each basin. The times series of runoff, hourly rainfall, daily evaporation, irrigation supply, and withdrawals are stored in the HECDSS data file.

Table C-4 presents a list of land use-specific hydrology parameters and calibration values used in the HSPF model developed for the St. Lucie River and Estuary watershed. INFILT is the infiltration, CEPSC is the interception storage capacity, UZSN is the upper zone nominal storage, LZSN is the lower zone nominal storage, and LZETP is the lower zone evapotranspiration.

Table C-4. Land Use-Specific Hydrology Parameters Used in the HSPF for the St. Lucie Watershed

Parameter	Definition	Units	Urban/Pasture	Groves	Forests	Wetlands
INFILT	Infiltration	inches per hour	0.08	0.10	0.12	0.04
CEPSC	Interception storage capacity	inches	0.10	0.14	0.10	0.10
UZSN	Upper zone nominal storage	inches	0.30	0.60	0.60	0.20
LZSN	Lower zone nominal storage	inches	3.00	3.00	3.00	2.50
LZETP	Lower zone evapotranspiration		0.30	0.45	0.50	0.45

Table C-5 presents a list of wetland hydrology parameters and calibration values used in the HSPF model developed for the St. Lucie River and Estuary watershed. Wetlands are assumed to lie at a lower mean elevation (MELEV), resulting in a lower zone nominal storage (LZSN), and the interflow parameter (INTFW) is set to zero and the interflow recession constant (IRC) is set equal to base flow recession. The flag value for selecting the algorithm for computing surface runoff from the wetland category is RTOPFG. If RTOPFG is 1, routing of overland flow is done in the same way as in the predecessor models Hydrocomp Simulation Programming version X (HSPX), Agricultural Runoff Management (ARM), and Nonpoint Source (NPS). A value of 2 results in use of a simple power function method. If a value of 3 is entered, the program uses a table in the function tables (FTABLES) block to determine surface outflow as a function of surface storage. The parameter STABNO gives the identification number to be found in the FTABLES block of the user's control input file. If STABNO is 1 for the wetlands, Function Table 1 is used for runoff from the wetland. The recession constant is SRRC and the recession exponent is SREXP. These parameters are used to relate surface runoff to surface storage. .

Table C-5. Land Use-Specific Hydrology Parameters Used in the HSPF for the St. Lucie Watershed

Parameter	Definition	Units	Urban/Pasture	Groves	Forests	Wetlands
RTOPFG	Flag value for surface runoff		2	2	2	3
INTFW	Interflow parameter		1.00	1.00	1.00	0.00
IRC	Interflow recession constant	per day	0.90	0.95	0.90	0.99
MELEV	Lower mean elevation		27.00	27.00	27.00	24.70
STABNO	FTABLES identification number		-	-	-	1
SRRC	Recession constant	per hour	0.90	0.90	0.90	-
SREXP	Recession exponent		1.00	1.00	1.00	-
IFWSC	Interflow storage capacity	inches	1.00	1.00	1.00	1.00

RCHRES MODULE

The channel/reservoir routing section (RCHRES) module is used if daily flow, daily stage data, and channel cross-sections were available. These data help to better define the storage available in the existing basin. If no measured historical data is available for model calibration, the RCHRES module is not used and the black box approach is used for that basin. The RCHRES module was used in the C-23 and C-24 basins when data was available.

Numerous pumps and culverts connect the project canal with the secondary drainage ditches in the land adjacent to the canal. Citrus areas represent the most intensive drainage network because of their flood protection and water supply needs. Pumps are most common for the citrus lands and, in general, the drainage capacity was designed to remove 2 inches per day of runoff from their land. Due to a lack of field data, assumptions were made for the secondary and tertiary canals. These assumptions are listed in **Table C-6**.

Table C-6. Assumptions for Secondary and Tertiary Canals Used in the RCHRES Module

Canal Type	Cross-Section		Side Slope	Lowest Bottom Elevation (feet NGVD)	Total Channel Length per Square Mile Area (miles)
	Bottom Width (feet)	Elevation (feet NGVD)			
Typical Citrus					
Secondary	35	18	1 vertical on 2 horizontal	14	3
Tertiary	10	20	1 vertical on 2 horizontal		10
Nongrove					
Secondary	20	19	1 vertical on 2 horizontal	14	1
Tertiary	5	21	1 vertical on 5 horizontal with depth		2

A function table was then developed for both citrus and nongrove lands. The flow rates were adjusted during a calibration process based on a simulation of 31 plus years of daily data at the S-49 and S-97 structures.

Basins such as C-23 and C-24 were divided into three RCHRES sections. All citrus PERLND water are discharged into an RCHRES with an function table developed for that land use. Another RCHRES is used for nongrove lands. Water from both citrus and nongrove RCHRES were routed through the most downstream RCHRES, which is the project canal, before discharging into the estuary. The function table for the project canal was developed based on the most recent surveyed cross-sectional data available for the C-23 and C-24 Canals. Additional RCHRES can be incorporated into the model when additional secondary channel data become available.

CALIBRATION AND MODEL RESULTS

Calibration was performed on the C-24 basin for the years from 1980 to 1992 by Aqua Terra Consultants, Inc., and Kraeger Associates in 1997. The simulated outflow was compared directly with the observed flow values. Several factors were discussed and were considered as problematic. These factors were further investigated and improved by the SFWMD staff during 1998. The District's continuing efforts are described in the following paragraphs.

Problem 1: Irrigation Application Data Not Available

The irrigation application amounts, timing, and sources are not available. A method of estimating the irrigation applied to groves was developed and relies on several assumptions regarding irrigation method, and irrigation and rainfall efficiency in meeting the demand. This approach, as presented in the 1997 report (Aqua Terra Consultants, Inc., and Kraeger Associates, 1977) was not considered satisfactory. For this reason, irrigation withdrawal from project canals was estimated using daily stage, flow, and channel cross-section data adjusted by an 40 percent (see the **Supplemental Irrigation** section on **page 13**). This 40 percent was included to represent water from deep ground water.

Problem 2: Unreliable Flow Data

The discharge rating curves for the S-49 structure used in the calibration simulations were updated using 12 flow measurements. The missing data or the data that had not been processed were recomputed by SFWMD staff. However, the quality of flow data for the S-49 and S-97 structures is considered fair. **Tables C-7** and **C-8** present the monthly runoff coefficients based on the ratio of observed runoff and rainfall over the C-23 and C-24 basins. The runoff coefficients that exceed 50 percent are not considered reliable. **Tables C-7** and **C-8** indicate that over 20 percent of the monthly data is not considered reliable. However, this is the best available data and nothing further can be done to improve its quality.

Table C-7. Monthly Runoff Coefficients for the C-24 Basin Based on Observed Runoff Rainfall Ratio

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1965	0.00	9.03	4.04	0.00	0.00	0.00	7.68	1.95	15.38	18.22	28.11	1.87	86.27
1966	36.55	41.01	31.48	2.23	14.59	22.87	36.69	54.18	15.40	74.61	0.00	4.59	334.20
1967	0.00	7.57	0.00	0.00	0.00	12.40	13.25	1.07	38.50	22.79	11.58	0.00	107.16
1968	0.00	0.00	0.00	0.95	28.40	68.07	23.66	3.36	10.85	24.81	18.47	0.00	178.57
1969	75.72	25.20	41.49	81.00	16.91	23.56	15.40	90.98	65.64	52.05	93.48	94.29	675.71
1970	202.76	102.91	49.00	428.92	0.08	9.63	20.11	28.53	23.58	49.90	37.81	0.00	953.22
1971	0.00	4.55	48.85	0.00	0.15	9.32	36.40	31.06	58.97	42.17	101.07	9.89	342.42
1972	15.45	20.42	15.59	34.25	22.14	36.25	13.61	14.11	23.73	7.44	11.66	47.27	261.92
1973	25.51	39.39	17.23	19.96	6.06	23.00	26.05	35.37	51.51	62.66	870.40	10.58	1,187.73
1974	0.00	0.00	0.00	0.00	0.00	14.16	54.60	77.05	27.09	45.09	15.22	18.73	251.93
1975	39.14	0.00	0.00	0.00	12.79	18.90	29.92	30.26	28.39	53.06	30.31	24.97	267.74
1976	18.76	4.27	58.63	19.59	22.03	59.93	35.42	18.68	25.45	52.18	3.13	19.98	338.06
1977	18.87	16.54	44.46	0.00	0.00	1.46	1.63	16.81	36.56	8.18	20.05	46.69	211.26
1978	35.73	26.24	32.48	4.15	6.26	14.06	19.34	34.64	14.13	22.46	14.52	18.24	242.24
1979	68.94	274.50	3.43	0.00	34.80	19.14	15.64	16.76	57.77	111.75	53.90	31.68	688.32
1980	8.64	22.15	8.25	24.86	5.72	5.29	7.25	4.79	29.88	0.00	0.80	2.20	119.82
1981	0.00	0.00	0.00	0.00	0.00	0.00	4.18	20.06	46.74	11.13	0.00	0.00	82.11
1982	0.00	4.91	30.32	49.07	42.67	78.28	77.81	62.27	61.20	69.76	34.85	28.90	540.04
1983	8.90	74.21	93.26	39.67	0.00	18.01	7.04	27.41	38.81	75.91	113.01	20.98	517.21
1984	231.50	24.42	23.19	10.32	7.92	9.98	36.82	34.51	34.22	78.61	34.14	186.73	712.35
1985	10.60	0.00	12.49	19.40	0.00	1.64	39.45	48.70	62.00	82.65	12.82	0.00	289.76
1986	12.79	0.00	6.32	0.00	0.00	24.40	39.81	70.62	31.37	18.75	47.79	4.61	256.46
1987	52.66	8.54	21.01	77.70	0.00	0.00	28.16	18.64	11.01	32.81	76.57	11.08	338.17
1988	5.50	30.47	17.65	0.00	15.26	7.64	22.24	35.44	35.19	0.00	0.00	0.00	169.39
1989	0.00	0.00	7.92	1.76	2.64	0.00	20.76	42.84	42.37	40.84	5.70	15.86	180.70
1990	72.87	18.28	19.44	0.00	0.00	8.57	36.48	35.76	46.04	150.42	23.97	0.00	411.82
1991	30.22	49.77	46.59	53.44	10.99	34.02	83.43	61.97	35.46	110.47	0.00	0.00	516.36
1992	0.00	0.44	0.00	0.00	0.00	28.73	71.65	51.07	56.72	65.78	29.01	21.04	324.42
1993	80.14	68.76	90.80	53.16	0.00	4.23	37.37	18.62	50.34	68.94	17.88	13.14	503.39
1994	27.06	78.64	34.69	7.76	26.29	74.75	30.46	54.97	55.48	61.78	61.80	83.76	597.45
1995	136.49	29.46	38.64	9.54	0.00	2.74	24.64	68.27	62.24	89.69	107.62	-0.12	569.21
Total	1,214.80	981.69	797.24	937.73	275.71	631.06	916.91	1,110.72	1,192.02	1,604.92	1,875.65	716.95	12,255.40

50 to 99%   >100%

Table C-8. Monthly Runoff Coefficients for the C-23 Basin Based on Observed Runoff Rainfall Ratio

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1965	0.00	22.15	26.40	6.66	3.65	0.16	17.90	44.35	29.06	39.10	88.88	10.65	288.97
1966	49.27	56.93	23.53	5.46	8.19	20.03	141.61	54.51	26.54	53.77	19.27	3.14	462.26
1967	0.74	5.13	10.46	13.16	0.00	9.38	30.95	15.38	9.38	12.55	8.59	0.00	115.72
1968	0.00	0.00	0.00	0.00	9.94	45.66	79.22	32.48	6.49	20.78	21.58	0.00	216.15
1969	1.42	3.51	20.46	6.53	12.89	67.79	36.29	64.45	42.04	72.10	174.00	53.09	554.56
1970	55.36	26.77	22.49	3,661.52	4.09	14.91	75.86	80.33	22.35	38.78	45.69	0.00	4,048.15
1971	0.00	0.00	0.00	0.00	0.00	1.19	20.77	37.44	25.46	32.02	58.92	6.14	181.94
1972	1.03	5.02	6.28	25.51	13.09	53.94	9.33	23.36	5.00	0.51	0.03	0.00	143.10
1973	0.57	35.36	16.08	0.84	0.58	38.56	26.16	25.37	48.69	35.44	338.42	68.05	634.13
1974	0.00	0.00	0.00	0.00	0.13	9.34	30.29	75.71	61.26	24.89	0.00	0.36	201.98
1975	0.00	1.03	1.80	11.22	10.83	23.58	29.25	32.49	21.77	42.63	0.00	0.00	174.59
1976	0.00	0.00	0.00	0.00	31.83	54.20	12.32	18.40	18.04	0.00	2.99	18.53	156.31
1977	21.91	24.65	1.23	0.41	2.05	2.35	4.63	14.08	25.55	3.58	35.63	37.03	173.12
1978	45.81	34.71	42.32	11.30	2.98	13.27	15.38	26.56	24.35	24.82	30.18	8.16	279.84
1979	65.76	213.01	12.00	0.72	5.91	9.07	16.99	14.16	41.60	92.95	17.52	31.27	520.94
1980	9.02	36.02	10.85	11.46	0.56	1.77	9.31	20.21	47.77	2.95	11.30	8.71	169.92
1981	1.42	11.40	0.36	2.99	0.39	0.95	1.93	24.08	4.07	1.55	14.14	26.90	90.20
1982	2.89	15.16	23.79	28.34	19.40	37.00	36.83	42.42	40.65	34.96	18.30	16.23	315.97
1983	4.78	53.65	62.51	24.38	2.02	6.76	6.31	17.98	43.88	48.19	61.74	13.49	345.68
1984	104.50	16.50	26.47	18.37	9.13	13.19	18.15	25.27	26.56	86.82	37.56	109.10	491.61
1985	0.00	0.00	12.72	15.95	0.00	0.18	24.72	48.34	47.58	76.47	22.34	2.81	251.11
1986	29.86	10.88	10.53	0.00	6.25	36.54	44.20	53.86	59.18	23.58	21.20	19.40	315.48
1987	71.38	19.78	30.60	165.85	0.36	0.66	9.05	9.17	11.22	25.51	42.53	784.80	1,170.92
1988	18.21	28.77	16.07	1.95	2.35	-3.24	6.19	7.57	29.97	5.58	8.39	-20.37	101.44
1989	7.41	-44.51	0.00	0.00	0.00	0.00	0.49	23.12	-4.77	-4.25	0.00	-7.75	-30.27
1990	0.00	0.00	0.00	0.00	-8.32	11.61	8.47	5.97	4.51	11.71	36.66	3.55	74.17
1991	21.55	-9.07	55.25	29.76	57.66	32.33	28.63	66.36	76.62	39.96	0.00	7.31	406.36
1992	0.00	0.50	0.00	0.00	0.00	17.80	57.76	54.24	51.41	108.44	59.75	79.97	429.87
1993	58.62	59.90	62.66	67.28	5.96	14.11	23.32	17.90	32.31	-2.99	14.32	6.81	360.20
1994	21.76	48.69	28.67	26.93	42.78	57.77	36.23	34.26	50.45	45.83	51.03	41.83	486.22
1995	23.47	15.24	26.47	0.02	0.00	4.16	23.11	59.72	56.29	82.32	35.82	0.00	326.62
Total	616.71	691.16	549.99	4,136.59	244.71	595.01	881.66	1,069.54	985.30	1,080.59	1,276.79	1,329.22	13,457.27

missing | 50 to 99% | >100%

Problem 3: Hourly Rainfall Station Data Gaps and Discrepancies

The hourly rainfall station data has many gaps. Also, the interior gages such as Cow Creek Ranch, Hayes Property, and Bluegoose tend to register lower rainfall amounts, an average of 12 to 17 inches per year lower, than the other stations. In 1998, an effort was made to verify data and fill the data gaps.

The soil parameter values were first evaluated based on the assumption of no irrigation withdrawals from local resources and no RCHRES option in place. This scenario is designated as Simulation 1. Under this scenario, if the simulated monthly flow compared favorably with the observed monthly flow at the S-49 and S-97 structures, then the parameter values used in the model will be considered reasonable. The values in general are not much different from the values used by the Aqua Terra Consultants in their 1997 study except the upper and lower influence elevations were slightly reduced.

Figures C-3 and **C-4** present the comparison of observed and simulated monthly flows at S-97 under Simulation 1. In general, good agreement exists for wet season months. The simulated flow during the dry season tends to be higher than the observed flow. This is reasonable because the irrigation and RCHRES option were not applied. The farmers conserve water for their irrigation needs during dry months and water is withdrawn from the canal system. Therefore, less runoff is being released through the main water control structures such as S-49 and S-97.

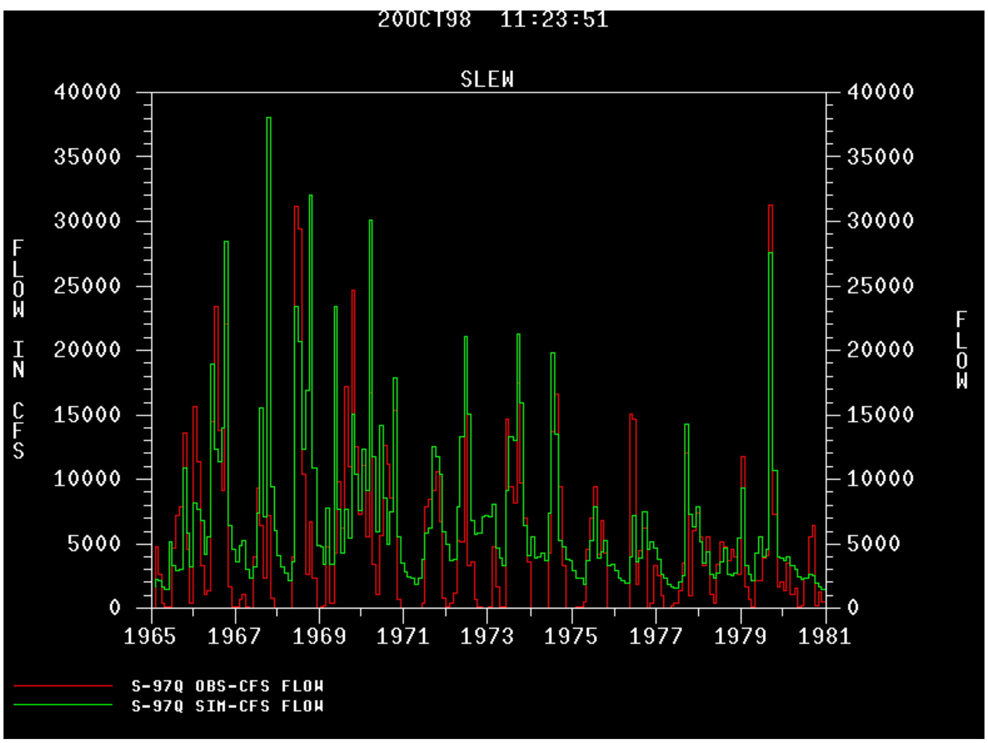


Figure C-3. Observed and Simulated Monthly Flow at the S-97 Structure without the Irrigation Scheme for the Period from 1965 to 1980

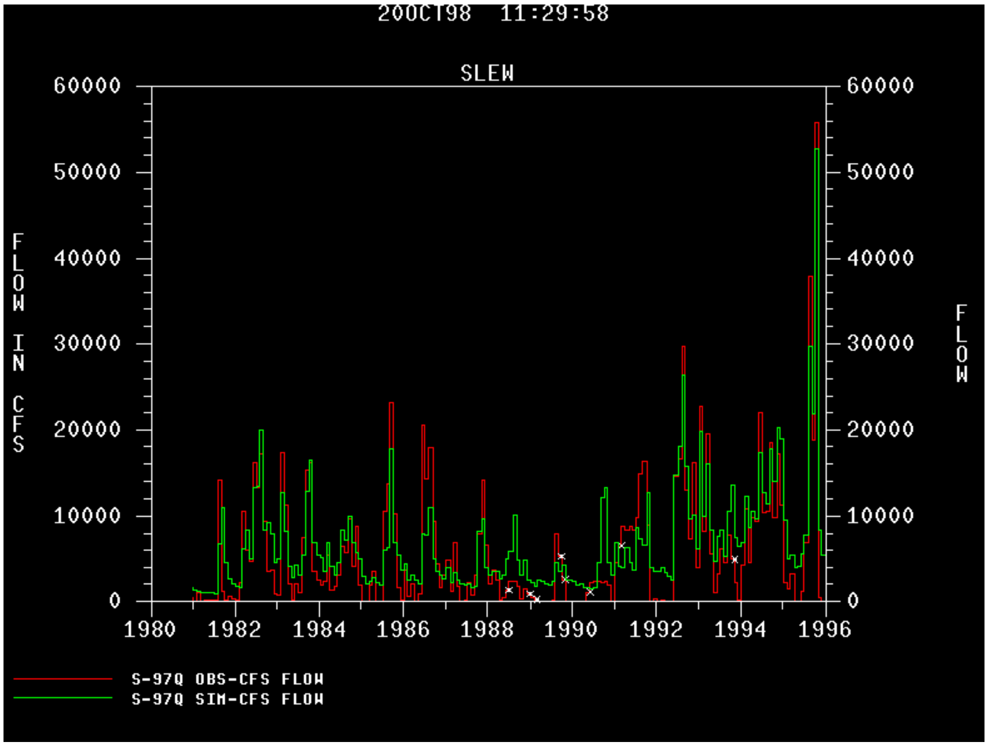


Figure C-4. Observed and Simulated Monthly Flow at the S-97 Structure without the Irrigation Scheme for the Period from 1981 to 1995

Figures C-5 and **C-6** presents the comparison of observed and simulated monthly flows at S-97 under Scenario 2. Under this scenario, the supplemental irrigation and RCHRES option are included in the model simulation and the results are much better for both wet and dry seasons. The irrigation withdrawn from the C-24 Canal not only irrigates citrus within the C-24 basin, it also irrigates the farms located within the North St. Lucie Water Control District. The amount of water and irrigated acreages are not available, so the estimation of total surface water irrigation for the C-24 basin presented in the water budget at the end of this appendix may be too high.

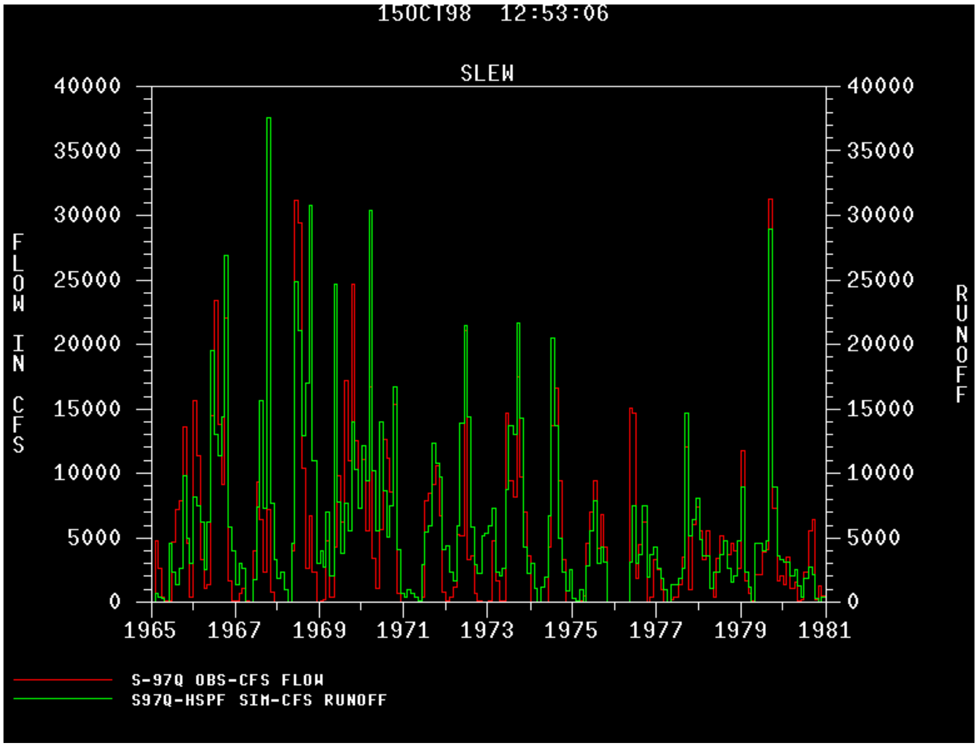


Figure C-5. Observed and Simulated Monthly Flow at the S-97 Structure with the Irrigation Scheme for the Period from 1965 to 1980

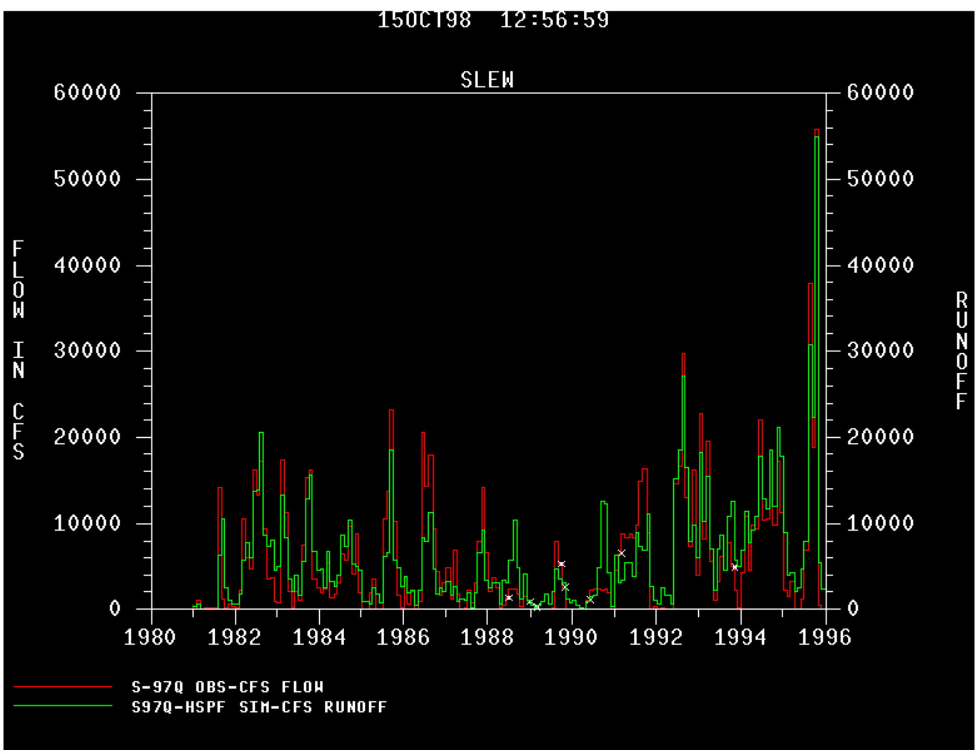


Figure C-6. Observed and Simulated Monthly Flow at the S-97 Structure with the Irrigation Scheme for the Period from 1981 to 1995

Figures C-7 through **C-9** present the comparison of daily observed and simulated stage at S-97, which is an automatic gated structure. The gate opens and closes according to the incoming flow and water level upstream of the structure. The daily flow goes up and down rather quickly due to the gate rapidly opening and closing. The rapid widening and contracting of the flow pathway caused by the gate opening and closing cannot be simulated correctly by the model. In the model, the discharge releases were based on structure capacity limits, optimum stage, and the amount of incoming runoff. This may explain why the daily simulation tends to produce smaller flows than observed conditions.

Another difference between actual operation of the structure and the simulated operation of the structure is the stage maintained within the canal. During simulations, a seasonal optimum stage was maintained in the project canal. For example, in the C-23 Canal, stage was maintained at 20.5 to 22.2 feet NGVD during the wet season (May 15 to October 15) and 22.2 to 23.2 feet NGVD during dry season (October 16 to May 14). However, this schedule was not followed exactly every year by the District's operation staff (**Figures C-7** through **C-9**).

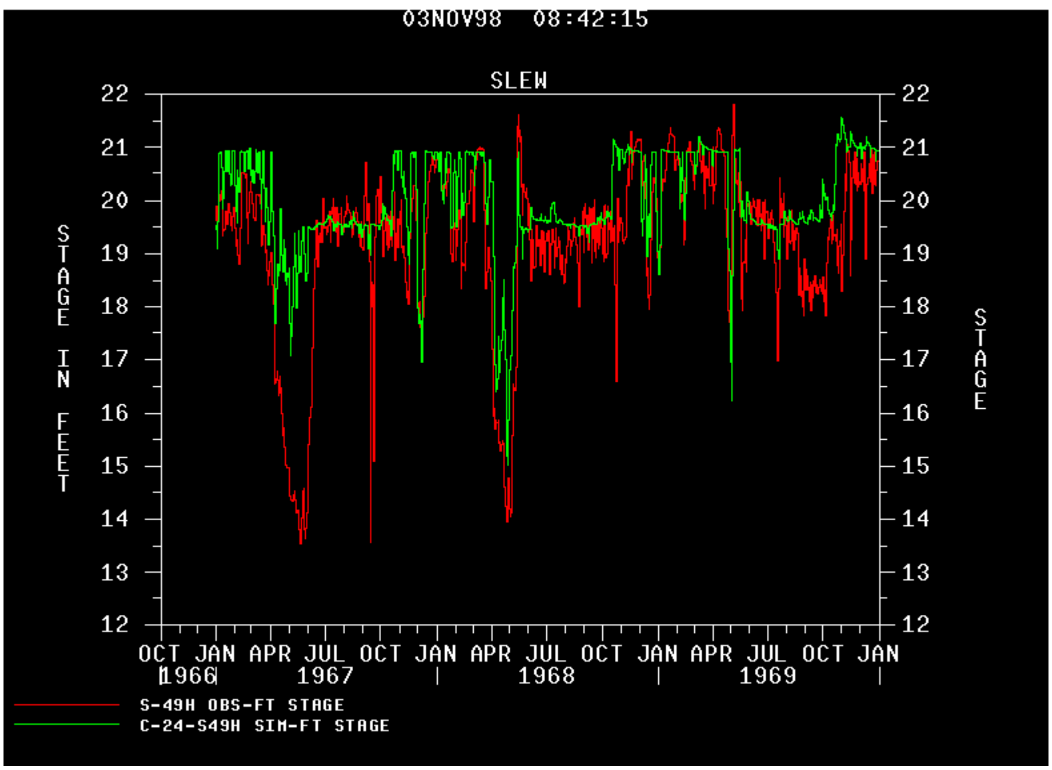


Figure C-7. Comparison of Observed and Simulated Daily Stage at the S-49 Structure for the Period from 1966 to 1969

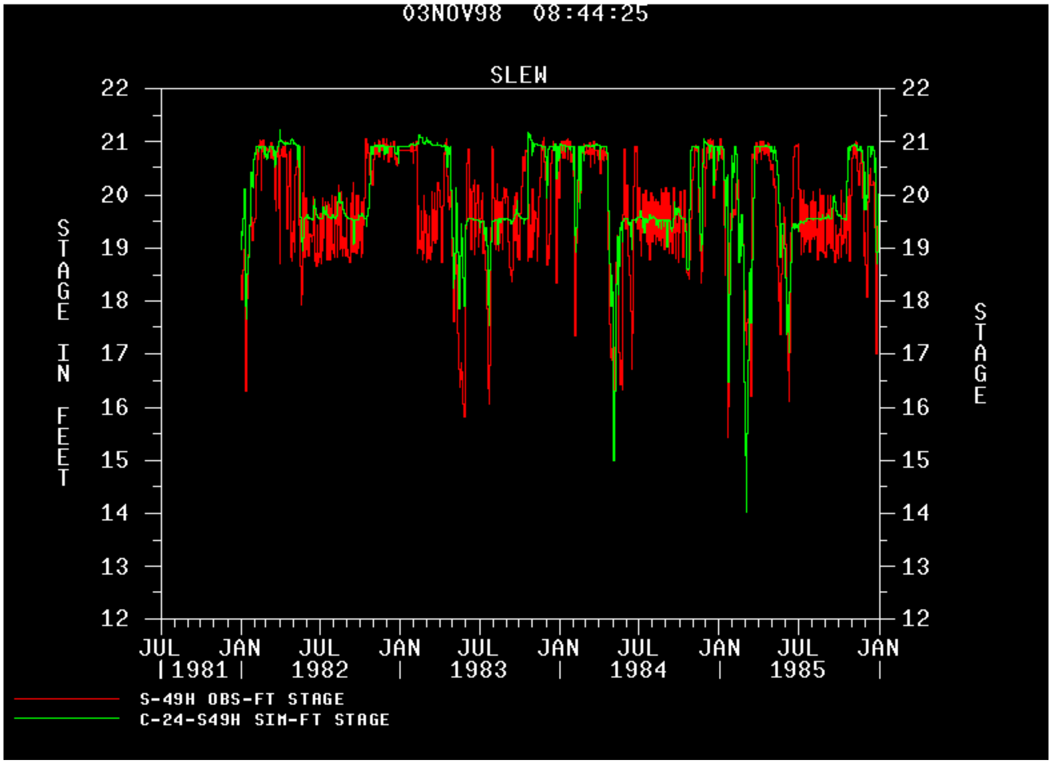


Figure C-8. Comparison of Observed and Simulated Daily Stage at the S-49 Structure for the Period from 1981 to 1985

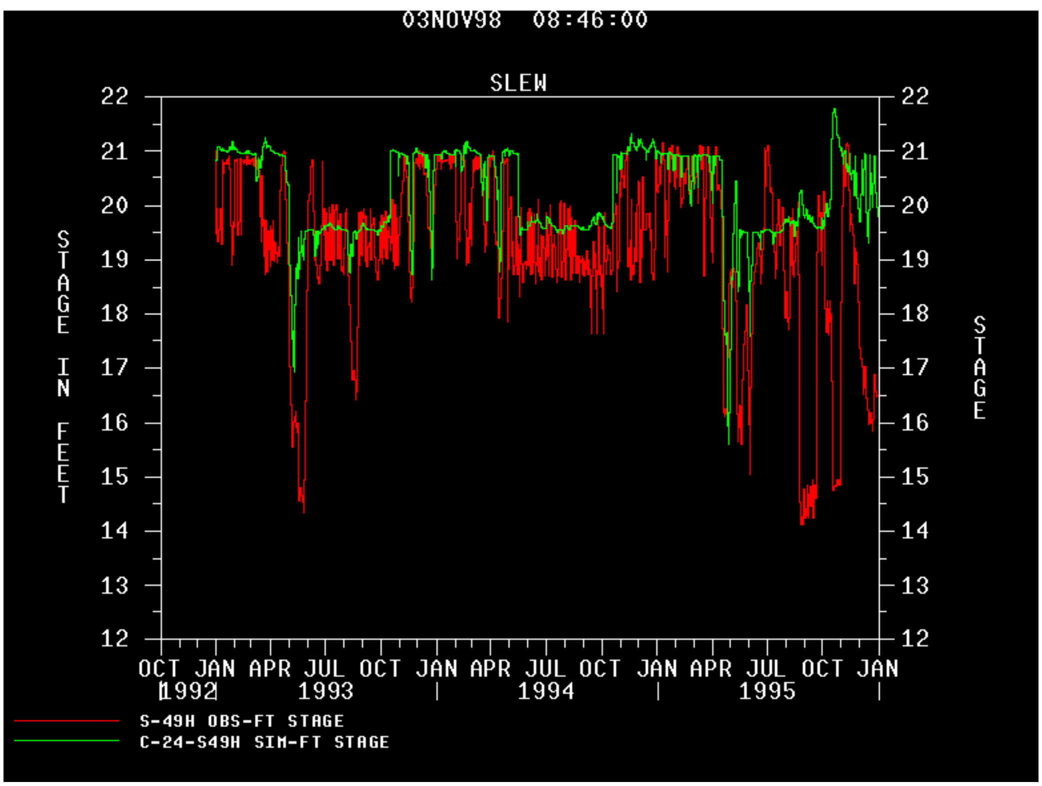


Figure C-9. Comparison of Observed and Simulated Stage at the S-49 Structure for the Period from 1992 to 1995

Figure C-10 presents a comparison of observed and simulated monthly flow frequency curves at S-97. Both curves are fairly close except for the low flow conditions. Noted that several months of observed data are missing.

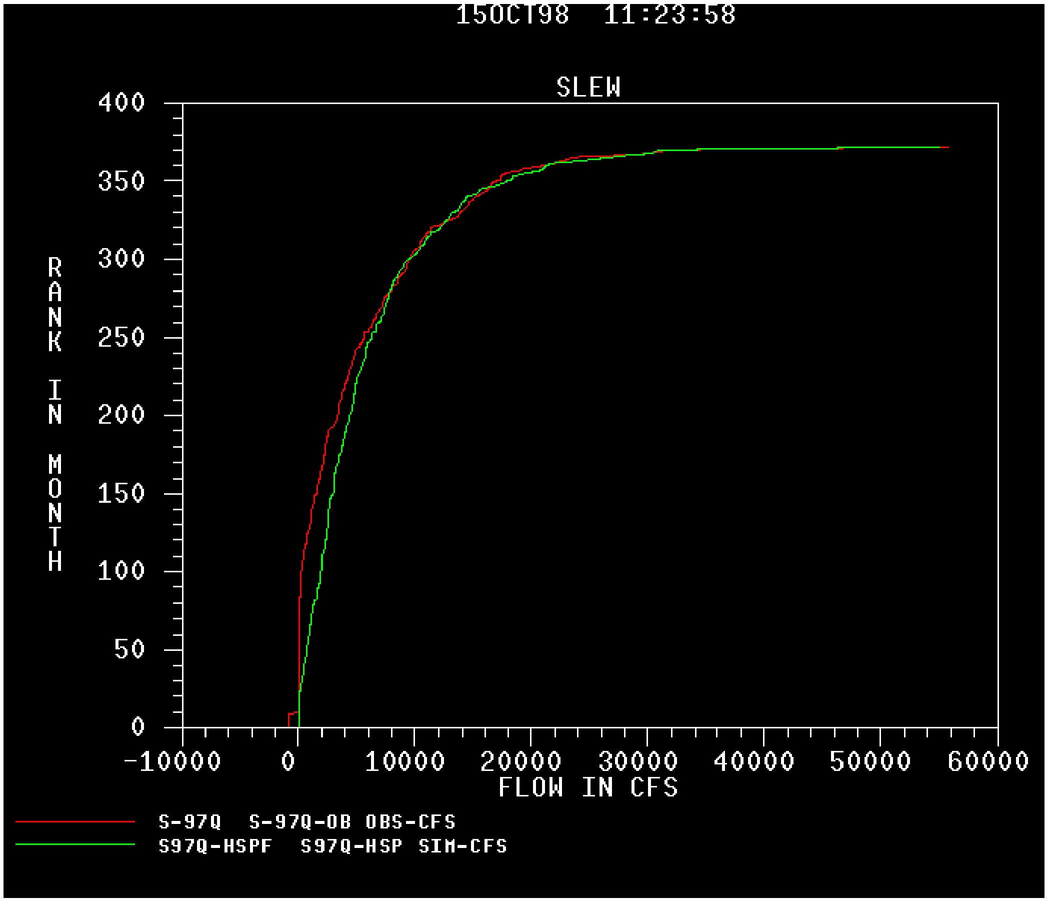


Figure C-10. Comparison of Observed and Simulated Monthly Flow Frequency Curves at the S-97 Structure

Figure C-11 presents the comparison of observed and simulated average monthly flow from the C-23 basin under Scenario 1 and Scenario 2. The simulated values tend to be slightly higher due to the assumption used for land uses. The land use of 1994 was used throughout the period from January 1965 through December 31, 1995, even though developed area has increased substantially since 1965.

The simulation results may be improved further by better estimation of daily supplemental irrigation and ground water withdrawals based on seasonal demand. However, this improvement would not be substantial enough to justify the additional efforts it would require.

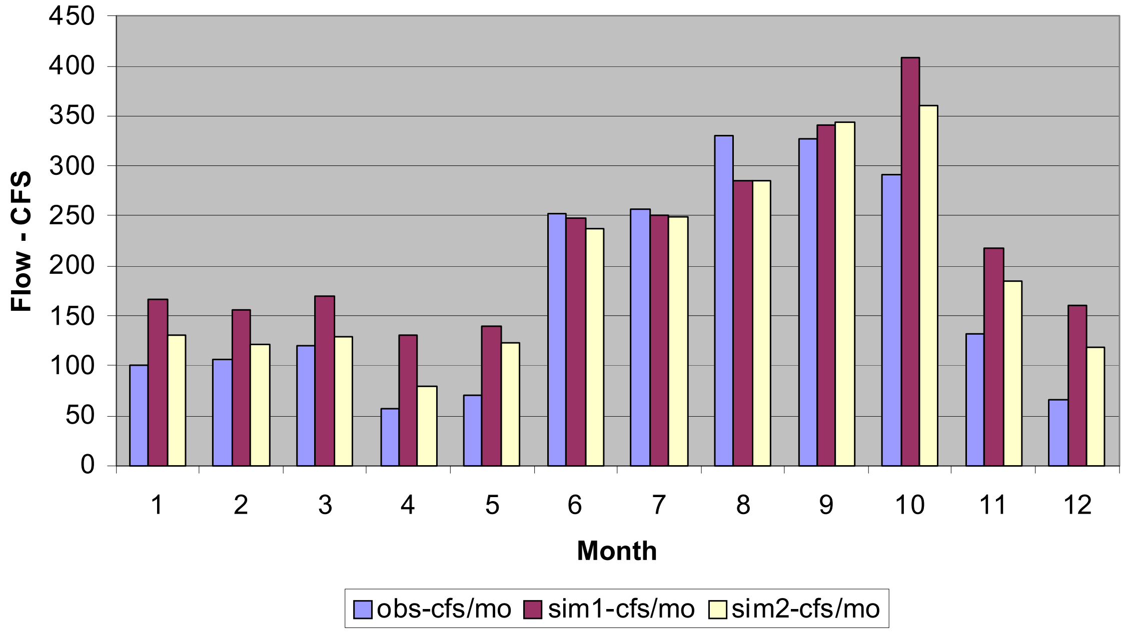


Figure C-11. Comparison of Observed and Simulated Average Monthly Flows from the C-23 Basin

Figures C-12 and **C-13** present comparisons of observed and simulated monthly flow at the S-49 structure located in the C-24 basin under Scenario 2 for the period beginning January 1965 and ending December 1995. **Figure C-14** presents a comparison of observed and simulated average monthly flow for the C-24 basin. **Figure C-15** presents a comparison of observed and simulated monthly flow frequency curves for the S-49 structure.

Figures C-16 through **C-18** present a comparison of observed and simulated daily flow and stage data at S-49. In general, the observed and simulated stage values are in agreement, but the daily flow has less agreement for the same reasons explained previously.

Overall, the results indicate that the parameter values used in the C-23 and C-24 basins can be applied to the rest of the St. Lucie Estuary watershed for model calibrations and applications when no observed data is available.

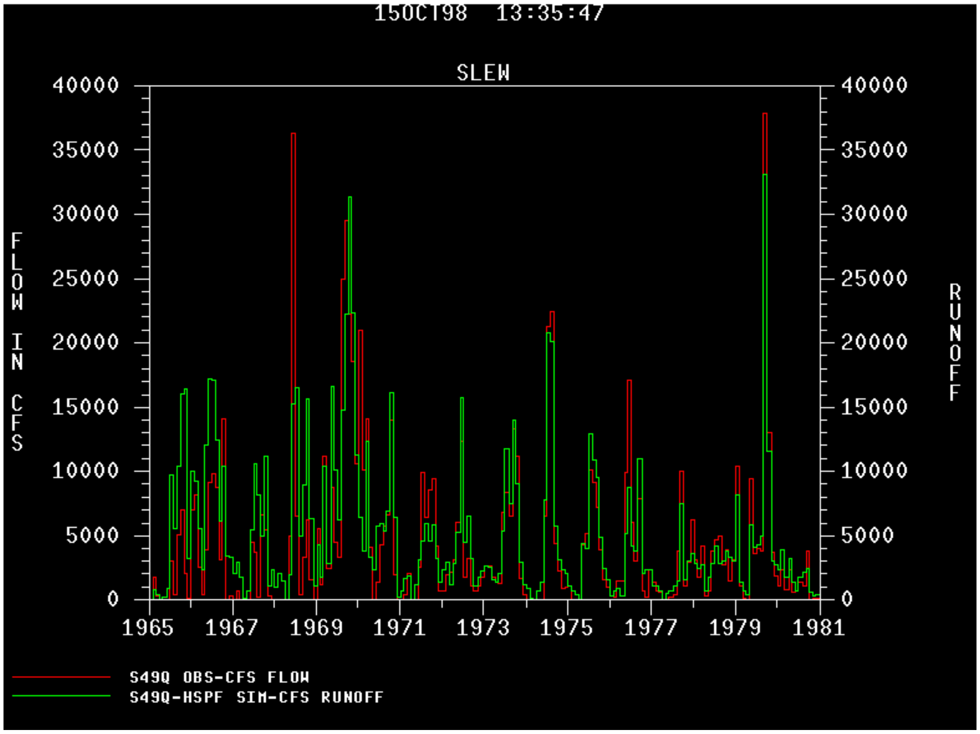


Figure C-12. Observed and Simulated Monthly Flow with the Irrigation Scheme for the Period from 1965 to 1980

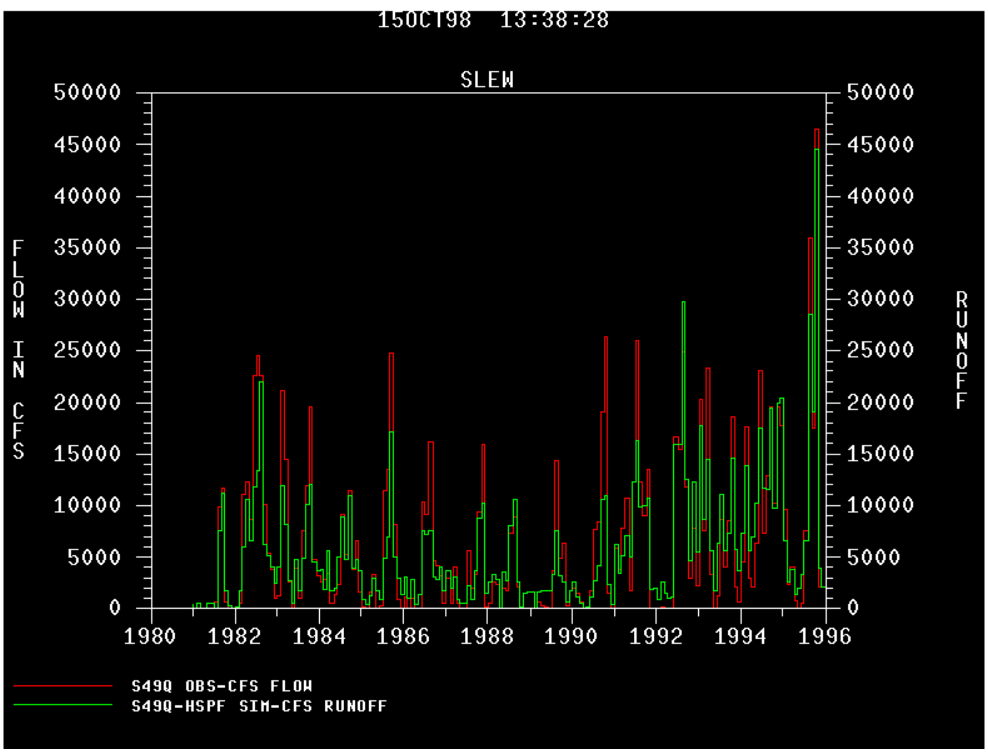


Figure C-13. Observed and Simulated Monthly Flow with the Irrigation Scheme for the Period from 1981 to 1995

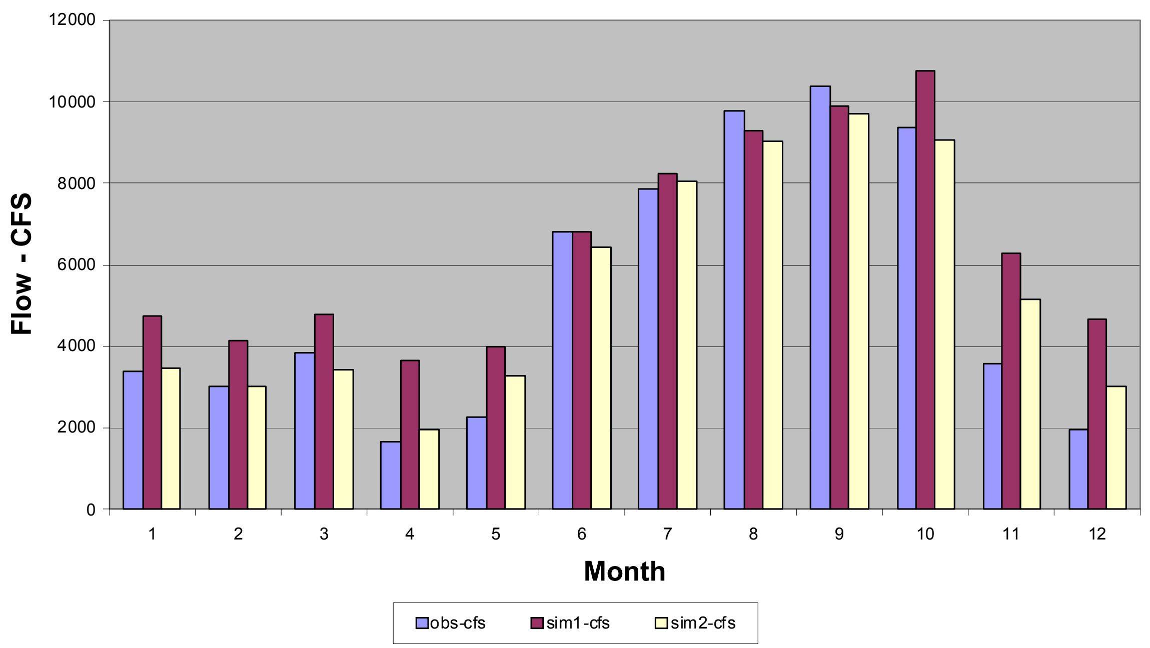


Figure C-14. Comparison of Observed and Simulated Averaged Monthly Flows from the C-24 Basin

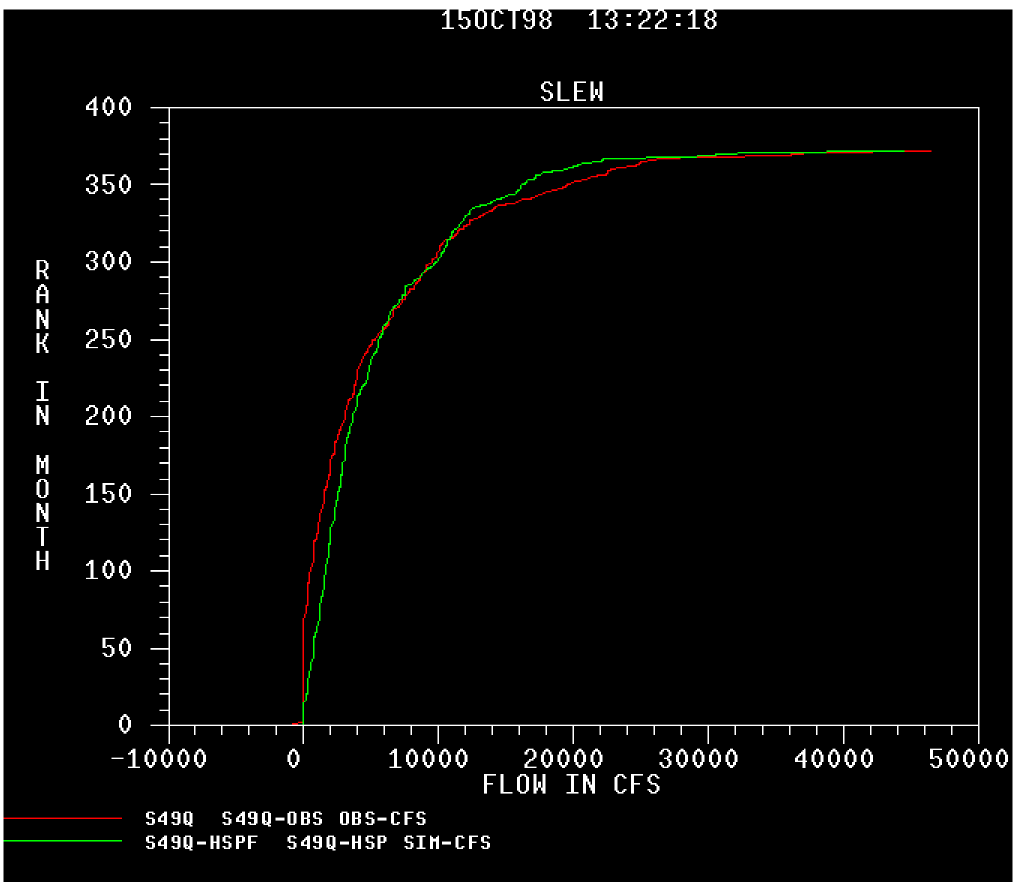


Figure C-15. Comparison of Observed and Simulated Monthly Frequency Curves at the S-49 Structure

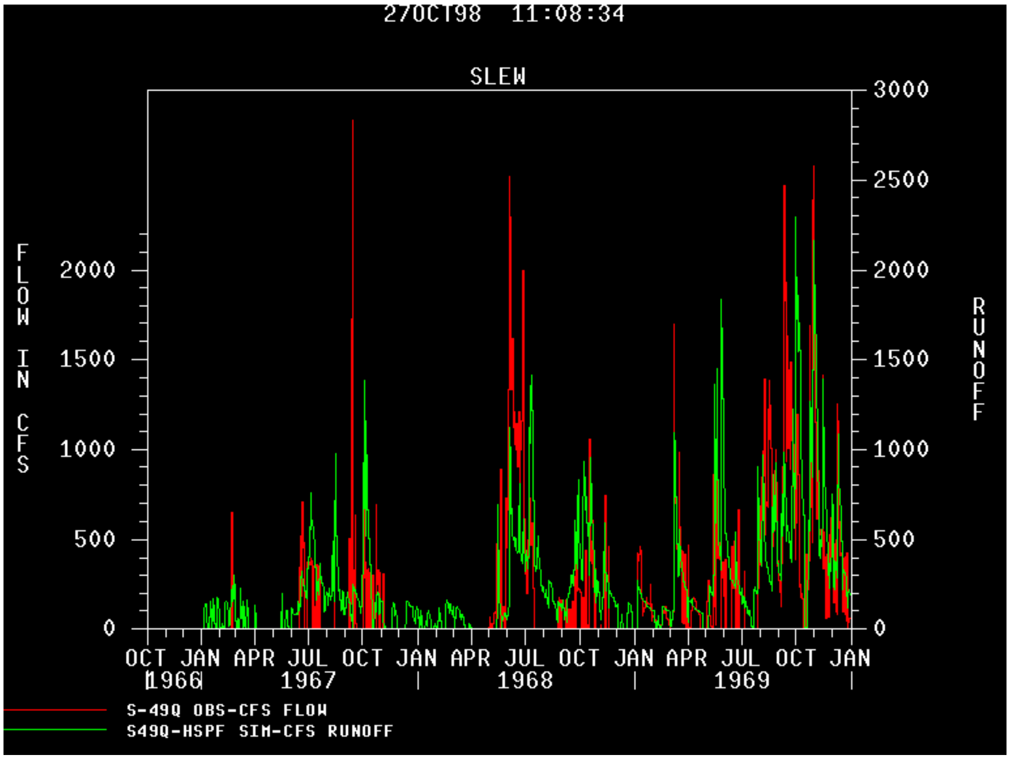


Figure C-16. Comparison of Observed and Simulated Daily Flow at the S-49 Structure for the Period from 1966 to 1969

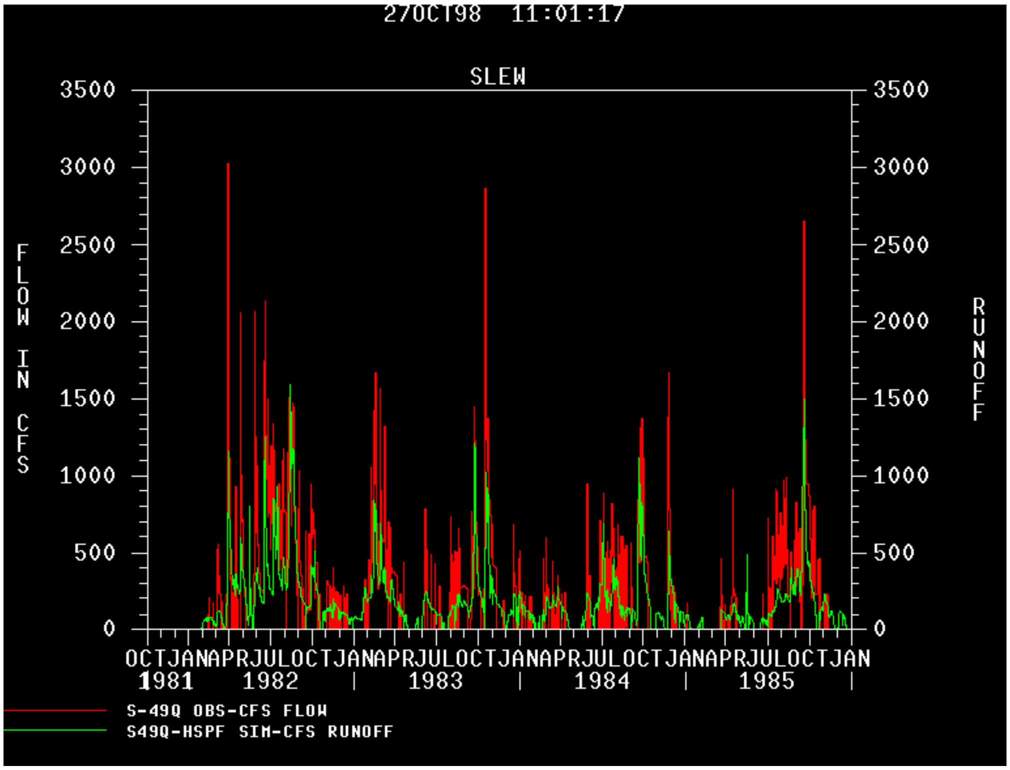


Figure C-17. Comparison of Observed and Simulated Daily Flow at the S-49 Structure for the Period from 1981 to 1985

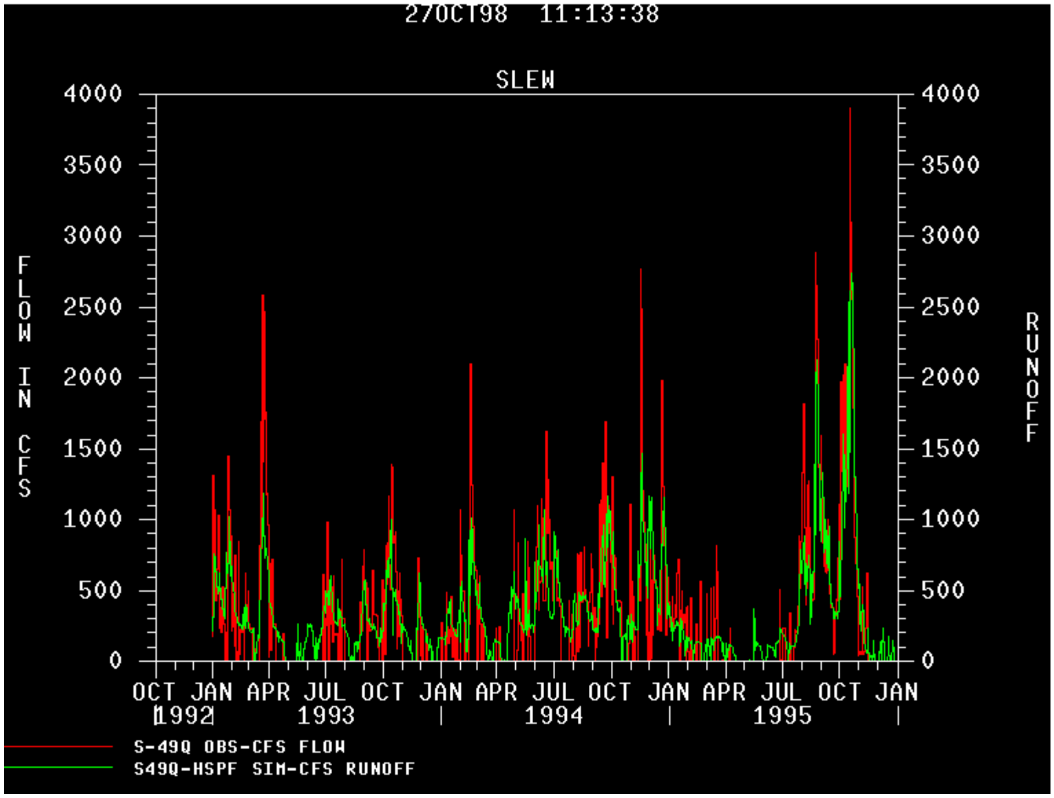


Figure C-18. Comparison of Observed and Simulated Daily Flow at the S-49 Structure for the Period from 1992 to 1995

WATER BUDGET FOR THE ST. LUCIE ESTUARY WATERSHED

Table C-8 presents the completed water budget for the watershed based on the HSPF modeling analysis. Water budgets for each basin within the watershed are provided in **Tables C-9** through **C-16**. The HSPF model has a built-in water budget balance check at each time step. The slight unbalance shown in the table was primarily caused by truncation and runoff error within the spreadsheet.

Table C-9. Water Budget for the St. Lucie Watershed

Parameter	Actual Values (inches per year)	Water Budget Calculations: inches per year	Water Budget Calculations: acre-feet per year
Rainfall	52.17	52.17	2,169,613
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	35.31	-35.31	-1,468,361
Irrigation			
From stream (71%)	2.48		
From Floridan Aquifer[a] and Lake Okeechobee (29%)	1.44	1.44	59,945
Land Use Runoff	20.67		
Basin Runoff	18.32	-18.32	-761,883
Balance		-0.02	-686

Actual Evapotranspiration for Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	36.43	40,358	122,521
Groves	39.50	140,331	461,926
Pasture	34.51	141,140	405,913
Urban Impervious	10.17	29,982	25,413
Urban Pervious	34.88	44,951	130,663
Wetland	37.77	102,271	321,924
Basin Total	193.26	499,033	1,468,360
Basin Average	32.21		

Runoff from Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	15.84	40,358	53,278
Groves	26.39	140,331	308,653
Pasture	16.91	141,140	198,851
Urban Impervious	18.12	44,951	67,862
Urban Pervious	43.06	29,982	107,598
Wetland	14.49	102,271	123,528
Basin Total	134.81	499,033	859,770
Basin Average	22.47		

Irrigation

Source	inches per year for groves	acres	acre-feet per year	inches per year for basin
Stream	8.81	140,331	102,989	2.48
Floridan Aquifer and Lake Okeechobee	5.13	140,331	59,945	1.44
Total	13.94	140,331	162,934	3.92

a. Irrigation from the Floridan Aquifer is considered an external source

b. Approximate values

Table C-10. Water Budget for the C-23 Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations: inches per year	Water Budget Calculations: acre-feet per year
Rainfall	50.70	50.70	473,298
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	36.64	-36.64	-342,002
Irrigation			
From stream (71%)	2.32		
From Floridan Aquifer[a] and Lake Okeechobee (29%)	0.93	.093	8,655
Land Use Runoff	17.33		
HSPF Basin Runoff	15.28	-15.28	-142,643
Observed Basin Runoff	13.88		
Balance		-0.29	-2,692

Actual Evapotranspiration for Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	36.66	5,387	16,455
Groves	39.15	34,596	112,860
Pasture	34.85	47,128	136,876
Urban Impervious	13.42	1,273	1,423
Urban Pervious	34.85	1,887	5,480
Wetland	38.03	21,743	68,907
Basin Total	36.64	112,013	342,002

Runoff from Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	13.79	5,387	6,190
Groves	21.74	34,596	62,668
Pasture	15.61	47,128	61,302
Urban Impervious	37.29	1,273	3,954
Urban Pervious	15.61	1,887	2,454
Wetland	12.72	21,743	23,039
Basin Total	17.33	112,013	159,607

Irrigation

Source	inches per year for groves	acres	acre-feet per year	inches per year for basin
Stream	7.51	34,596	21,638	2.32
Floridan Aquifer and Lake Okeechobee	3.00	34,596	8,655	0.93
Total	10.51	34,596	30,293	3.25

a. Irrigation from the Floridan Aquifer is considered an external source
b. Approximate values

Table C-11. Water Budget for the C-24 Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations inches per year	Water Budget Calculations acre-feet per year
Rainfall	50.95	50.95	386,305
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	35.03	-35.03	-265,643
Irrigation From stream (71%) From Floridan Aquifer[a] and Lake Okeechobee (29%)	 3.20 1.28	 1.28	 9,697
Land Use Runoff	20.23		
HSPF Basin Runoff	17.16	-17.16	-130,092
Observed Basin Runoff	16.70		
Balance		0.04	267

Actual Evapotranspiration for Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	35.26	6,968	20,472
Groves	37.85	20,646	65,115
Pasture	33.70	41,827	117,476
Urban Impervious	13.52	1,184	1,333
Urban Pervious	33.70	1,775	4,986
Wetland	36.32	18,589	56,260
Basin Total	35.03	90,988	265,643

Runoff from Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	15.42	6,968	8,952
Groves		20,646	
Pasture	16.98	41,827	59,198
Urban Impervious	37.43	1,184	3,692
Urban Pervious	16.98	1,775	2,513
Wetland	14.65	18,589	22,691
Basin Total	20.23	90,988	153,401

Irrigation

Source	inches per year for groves	acres	acre-feet per year	inches per year for basin
Stream	14.09	20,646	24,242	3.20
Floridan Aquifer and Lake Okeechobee	5.64	20,646	9,697	1.28
Total	19.74	20,646	33,939	4.48

a. Irrigation from the Floridan Aquifer is considered an external source

b. Approximate values

Table C-12. HSPF Water Budget for the C-44 Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations	
		inches per year	acre-feet per year
Rainfall	53.26	53.26	515,258
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	38.32	-38.32	-370,744
Irrigation From stream (71%) From Floridan Aquifer[a] and Lake Okeechobee (29%)	 2.96 3.12	 3.12	 30,191
Land Use Runoff	21.03		
HSPF Basin Runoff	17.91	-17.91	-173,293
Observed Basin Runoff	NA[b]		
Balance		0.14	1,383

Actual Evapotranspiration for Each Land Use[c]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	37.28	7,490	23,265
Groves	40.77	48,873	166,049
Pasture	35.57	25,372	75,212
Urban Impervious	13.91	1,724	1,999
Urban Pervious	35.57	2,587	7,668
Wetland	38.57	30,049	96,581
Basin Total	38.32	116,095	370,774

Runoff from Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	16.02	7,490	10,000
Groves	26.63	48,873	108,469
Pasture	17.74	25,372	37,508
Urban Impervious	39.67	1,724	5,700
Urban Pervious	17.74	2,587	3,824
Wetland	15.00	30,049	37,568
Basin Total	21.03	116,095	203,069

Irrigation				
Source	**inches per year for groves**	**acres**	**acre-feet per year**	**inches per year for basin**
Stream	7.02	48,873	28,604	2.96
Floridan Aquifer and Lake Okeechobee	7.41	48,873	30,191	3.12
Total	14.45	48,873	58,795	6.08

a. Irrigation from the Floridan Aquifer is considered an external source

b. NA = Not available

c. Approximate values

Table C-13. HSPS Water Budget for the North Fork St. Lucie Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations: inches per year	Water Budget Calculations: acre-feet per year
Rainfall	53.24	53.24	464,665
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	32.42	-32.42	-282.970
Irrigation			
From stream (71%)	3.27		
From Floridan Aquifer[a] and Lake Okeechobee (29%)	1.31	1.31	11,402
Land Use Runoff	25.47		
HSPF Basin Runoff	22.20	-22.20	-193.777
Observed Basin Runoff	NA[b]		
Balance		-0.08	-680

Actual Evapotranspiration for Each Land Use[c]

Land Use	inches per year	acres	acre-feet per year
Forest	36.99	11,047	34,054
Groves	40.78	27,317	92,821
Pasture	35.13	5,448	15,953
Urban Impervious	8.71	18,916	13,074
Urban Pervious	35.13	28,373	83,074
Wetland	38.16	13,630	43,341
Basin Total	32.42	104,731	282,970

Runoff from Each Land Use[b]

Land Use	inches per year	acres	acre-feet per year
Forest	16.24	11,047	14,949
Groves	29.71	27,317	67,625
Pasture	18.11	5,448	8,222
Urban Impervious	44.76	18,916	70,552
Urban Pervious	18.11	28,373	42,815
Wetland	15.37	13,630	17,458
Basin Total	25.47	104,731	221,621

Irrigation

Source	inches per year for groves	acres	acre-feet per year	inches per year for basin
Stream	12.52	27,317	28,505	3.27
Floridan Aquifer and Lake Okeechobee	5.01	27,317	11,402	1.31
Total	17.53	27,317	39,907	4.57

a. Irrigation from the Floridan Aquifer is considered an external source
b. NA = Not available
c. Approximate values

Table C-14. HSPF Water Budget for the Tidal St. Lucie Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations	
		inches per year	acre-feet per year
Rainfall	53.71	53.71	212,775
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	33.31	-33.31	-131,941
Irrigation	0.00		
Land Use Runoff	20.23		
HSPF Basin Runoff	20.23	-20.23	-80,145
Observed Basin Runoff	NA[a]		
Balance		0.17	689
Actual Evapotranspiration for Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	35.87	4,548	13,592
Groves	34.06	6,409	18,193
Pasture	34.16	14,706	41,860
Urban Impervious	12.39	3,928	4,055
Urban Pervious	34.16	5,892	16,722
Wetland	37.30	12,053	37,468
Basin Total	33.31	47,537	131,941
Runoff from Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	17.56	4,548	6,654
Groves	19.44	6,409	10,385
Pasture	19.28	14,706	23,626
Urban Impervious	41.33	3,928	13,530
Urban Pervious	19.28	5,892	9,467
Wetland	16.41	12,053	16,484
Basin Total	20.23	47,537	80,145
Irrigation			
Irrigation for groves is assumed to be insignificant.			

a. NA = Not available
b. Approximate values

Table C-15. Water Budget for Basins 4, 5, and 6

Parameter	Actual Values (inches per year)	Water Budget Calculations	
		inches per year	acre-feet per year
Rainfall	53.91	53.91	66,268
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	31.62	-31.62	-38,865
Irrigation	0.00		
Land Use Runoff	22.11		
HSPF Basin Runoff	22.12	-22.12	-27,181
Observed Basin Runoff	NA[a]		
Balance		0.17	222
Actual Evapotranspiration for Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	36.29	3,491	10,559
Groves	34.74	420	1,217
Pasture	34.59	2,530	7,293
Urban Impervious	12.24	2,510	2,561
Urban Pervious	34.59	3,766	10,855
Wetland	37.67	2,033	6,381
Basin Total	31.67	14,750	38,865
Runoff from Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	17.34	3,491	5,046
Groves	18.96	420	664
Pasture	19.06	2,530	4,018
Urban Impervious	41.68	2,510	8,719
Urban Pervious	19.06	3,766	5,981
Wetland	16.26	2,033	2,753
Basin Total	22.11	14,750	27,181
Irrigation			
Irrigation for groves is assumed to be insignificant.			

a. NA = Not available

b. Approximate values

Table C-16. HSPF Water Budget for the S-153 Basin

Parameter	Actual Values (inches per year)	Water Budget Calculations	
		inches per year	acre-feet per year
Rainfall	47.41	47.41	51,045
Potential Evapotranspiration	64.00		
Actual Evapotranspiration	33.59	-33.59	-36,167
Irrigation	0.00		
Land Use Runoff	13.70		
HSPF Basin Runoff	13.70	-13.70	-14,746
Observed Basin Runoff	NA[a]		
Balance		0.12	132
Actual Evapotranspiration for Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	34.65	1,428	4,124
Groves	32.88	2,069	5,670
Pasture	32.68	4,129	11,244
Urban Impervious	8.47	447	316
Urban Pervious	32.68	671	1,828
Wetland	37.32	4,175	12,985
Basin Total	33.59	12,920	36,167
Runoff from Each Land Use[b]			
Land Use	**inches per year**	**acres**	**acre-feet per year**
Forest	12.49	1,428	1,486
Groves	14.42	2,069	2,486
Pasture	14.47	4,129	4,977
Urban Impervious	38.95	447	1,452
Urban Pervious	14.47	671	809
Wetland	10.16	4,175	3,534
Basin Total	13.70	12,920	14,746
Irrigation			
Irrigation for groves is assumed to be insignificant.			

a. NA = Not available
b. Approximate values

REFERENCES

Aqua Terra Consultants Inc., and Kraeger Associates. 1997. *St. Lucie Basin Model: Interim Calibration Report*. Contract C-3365, South Florida Water Management District, West Palm Beach, FL.

Coastal Environmental, Inc. 1994.

SCS. 1993. *Indian River Lagoon Agricultural Land-Use Inventory and Discharge Study.* Soil Conservation Service, United States Department of Agriculture, Gainesville, FL.

SFWMD. 1998. *Upper East Coast Water Supply Plan*. South Florida Water Management District, West Palm Beach, FL.

Smajstrla. 1990. *Technical Manual for the Agricultural Field-Scale Investigation Requirements Simulation Model, Version 5.5*. Agricultural Engineering Department, University of Florida, Gainesville, FL.

APPENDIX D
APPLICATION OF THE NATURAL SYSTEM MODEL TO THE ST. LUCIE WATERSHED

INTRODUCTION

Biological investigations of the St. Lucie and Caloosahatchee Estuaries led to an understanding of the relationship between important communities and flow from the watershed. This understanding formed the bases for the salinity envelope concept in which desired minimum and maximum mean monthly flow limits to the estuaries were defined with an "acceptable" number of violations of these limits. The scientific justification for these acceptable violations is weak and, therefore, needs additional investigations. It has been demonstrated with the optimization model that the amount of retention/detention needed in the watershed to obtain the desired flow to the estuaries is sensitive to the number of acceptable violations allowed, especially the upper violations. Basically, the greater amount of violations allowed, the less retention is needed in the watershed. Therefore, further insights in to the acceptable number of violations may have a major influence on the proposed amount of retention needed in the St. Lucie Estuary watershed. In addition, the effort to establish minimum flows and levels (MFLs) for the estuary is dependent on documenting significant levels of harm of low and high flow. This MFL effort needs to clearly demonstrate the potential impact of flows outside of the salinity envelope. Therefore, it is important to gain a better insight of the "acceptable" violations for several major South Florida Water Management District (SFWMD or District) concerns dealing with watershed management of the St. Lucie Estuary.

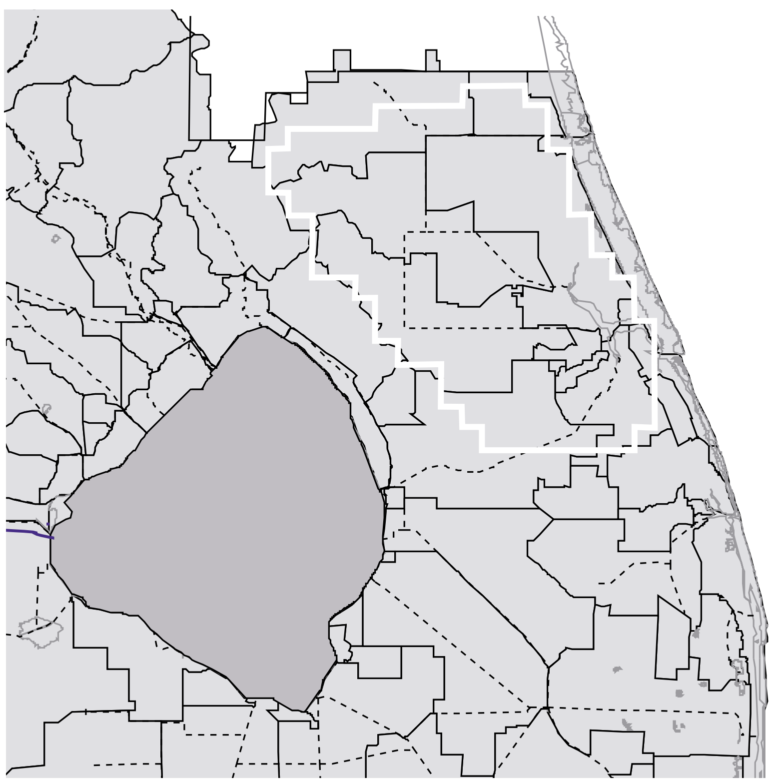
Two approaches to gaining a better understanding of the acceptable number of violations have been suggested. Both embrace the need to determine the natural distribution of flows to the estuary. The Peace River has a well defined historical flow record and has minimal impact from development. Therefore, the distribution of flows from this estuary will be determined and compared with suggested distribution of flows for the St. Lucie Estuary. Another method of determining the distribution of flows under natural conditions can be obtained by applying the Natural System Model (NSM) to the St. Lucie watershed. The NSM has been used successfully to simulate the predrainage condition in other parts of the District. This report summarizes the application of the NSM to the St. Lucie watershed.

MODEL SPECIFICATIONS

The NSM is a two-dimensional coupled surface-ground water model that incorporates the dominant physical processes affecting hydrology in South Florida. The model domain is discretized into grid cells, and the spatial properties required to simulate each of the hydrologic processes are estimated for each cell. Spatial properties include vegetation/landscape type, land surface elevation, aquifer depth and permeability, soil storage coefficient, and initial water level. Similarly, rivers are discretized into linear segments, and properties associated with each of the rivers are estimated. River properties include river location and dimension, outlet specifications, and coefficients for river to overland flow and river to aquifer interaction.

Model Domain

The domain of the St. Lucie NSM includes the areas that under "natural" conditions would have been drained by the St. Lucie River and its tributaries. The St. Lucie watershed includes portions of the following surface water management basins: C-23, C-24, C-25, C-44, North Fork St. Lucie River, and Tidal St. Lucie. The model boundary is generally aligned along surface water basin boundaries or in areas where surface water movement is low (**Figure D-1**). The principle outlets for excess water are the North and South Forks of the St. Lucie River, which in turn discharge to the St. Lucie Estuary.



Notes:
- Surface water management basins delineated by solid black lines
- Model domain delineated by white line
- Primary canals delineated by dashed lines

Figure D-1. Natural Systems Model Boundary Map for the St. Lucie Watershed

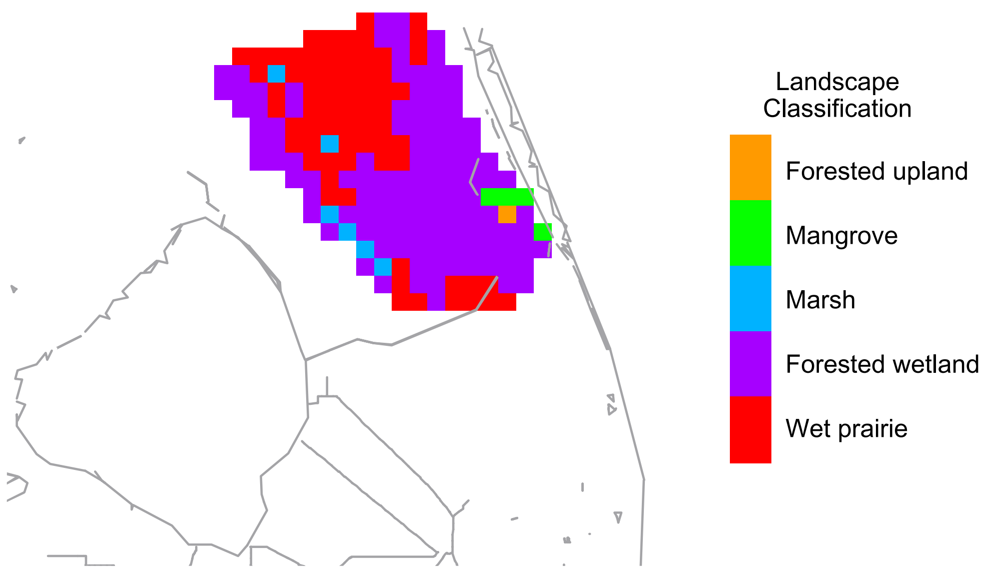
Vegetation

Cell vegetation type is based on soils information, specifically the Natural Landscape Position coverage (Zahina et al., 2001). The landscape classification is consistent with definitions contained in the NSM developed for South Florida. Five landscapes are identified in the St. Lucie watershed (**Table D-1**).

Table D-1. Landscape Classifications Used in the Natural Systems Model.

No.	Landscape	Description	Percent Area
1	Mangrove	Low coastal areas dominated by mangrove swamps with saltwater to brackish water marshes	2
2	Forested uplands	Pinelands on higher sands	1
3	Marsh	Fresh marshes outside the Everglades basin	3
4	Wet prairie	Mosaic landscape; sloughs densely filled with grasses; tree islands may be present	35
5	Forested wetlands	Cypress and hardwood swamps; wetter mosaics of pine flatwoods and depressional wetlands	59

The St. Lucie watershed lies with the Eastern Flatlands physiographic region. These flatlands had many shallow, usually just seasonally, wet ponds and long narrow sloughs (Davis, 1943). The characteristic landscape is either wet prairie or forested wetlands (**Figure D-2**). Model input parameter values for these landscape types are taken directly from the NSM (Version 4.5), whose parameter values are imported directly from the calibrated and verified South Florida Water Management Model (SFWMD, 1999).



Notes:
- Landscape homogeneous with a cell
- Canals and levees included for points of reference

Figure D-2. Landscape Map for the St. Lucie Watershed

Topography

Land surface elevation is based on available geographic information system (GIS) topographic coverages for this area. Land surface elevations in the St. Lucie watershed range from more than 60.0 feet along the western boundary to less than 4 feet near the St. Lucie Estuary (**Figure D-3**).

Notes:
- Elevations referenced to National Geodetic Vertical Datum (NGVD), 1927
- Contours based on cell-by-cell land elevation
- Contour line interval = 5.0 feet
- Contour shade interval = 2.5 feet

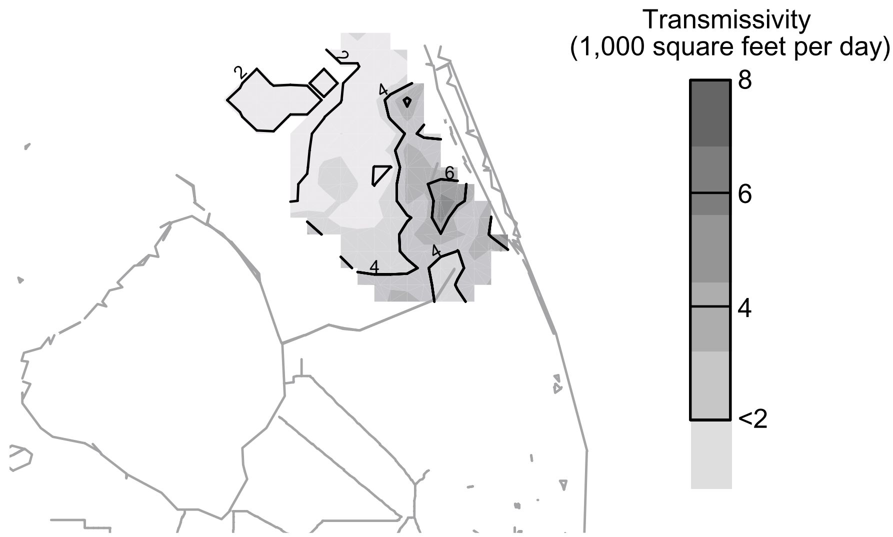
Figure D-3. Land Surface Elevation Map for the St. Lucie Watershed

Surficial Aquifer

Surficial aquifer properties for each cell are defined by aquifer transmissivity and soil storage coefficient values. Transmissivity is the product of aquifer depth and aquifer permeability, and ranges between 1,000 to 8,000 square feet per day (**Figure D-4**). Soil storage coefficient is uniformly set to 0.2 feet per foot

Rivers

The St. Lucie watershed contains rivers and creeks which cannot be represented by the relatively coarse two-by-two mile grid. These surface features are discretized into linear segments, and the impacted cells or river cells, are identified (**Figure D-5**). Outflow from a river is discharged to tide or to another river. Although much of the river system in the St. Lucie watershed has been excavated, the river location can be approximated from existing hydrography coverages.



Notes:
- Transmissivity = aquifer depth x permeability
- Contour line interval = 4,000 square feet per day
- Contour shade interval = 1,000 square feet per day
- Canals and levees included for points of reference

Figure D-4. Aquifer Transmissivity Map for the St. Lucie Watershed

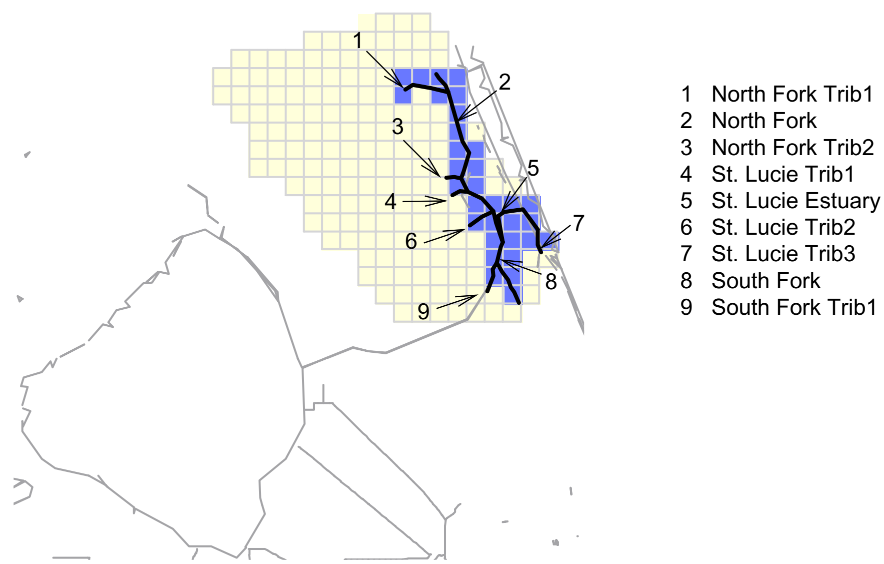


Figure D-5. Model Grid and River Location Map used in the Natural Systems Model for the St. Lucie Watershed

Initial Condition

The initial condition is established in the NSM by setting the initial water level in each cell and in each segment of the rivers. Initial cell water levels are set by uniformly setting the surface water ponding depth in marsh cells.

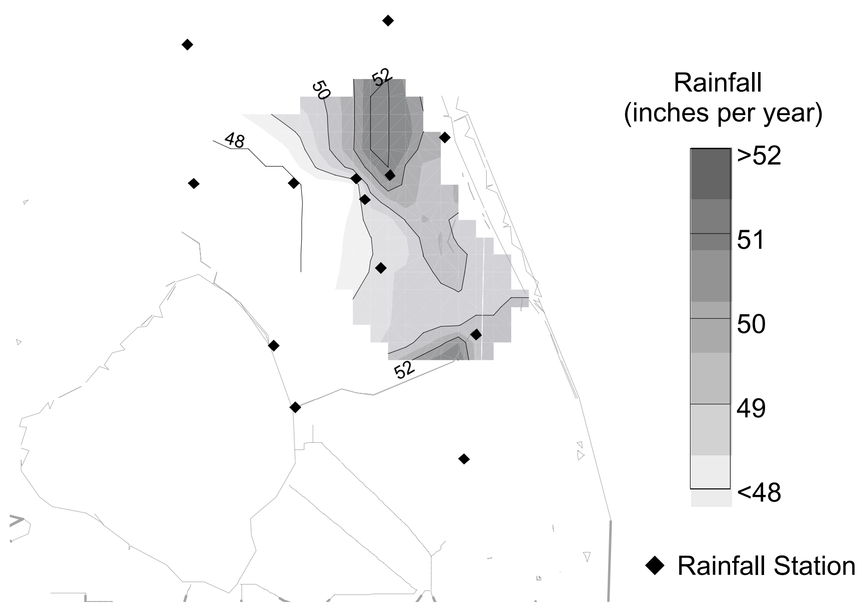
BOUNDARY CONDITIONS

Water levels in the model domain fluctuate in response to transient boundary conditions that are imposed on selected cells. Boundary conditions represent external driving functions that cause water to be added or removed from the model domain. Hydrology in South Florida is primarily driven by rainfall and evapotranspiration (Fennema et al., 1994). These boundaries are applied on a daily basis to every cell in the model domain.

Rainfall

The rainfall database consisted of 13 stations that reported data during the 1965 to 1997 simulation period (**Figure D-6**). Since data records may not be continuous at each station, daily rainfall for each cell is based on the nearest station with data.

Rainfall in South Florida varies seasonally, with distinct wet and dry seasons. Wet season rainfall results predominately from convective and tropical storms and dry seasons rainfall comes primarily from frontal systems. Rainfall also varies spatially, ranging from less than 47 inches per year in the extreme western cells to more than 56 inches per year along the coastal ridge (Sculley, 1986).



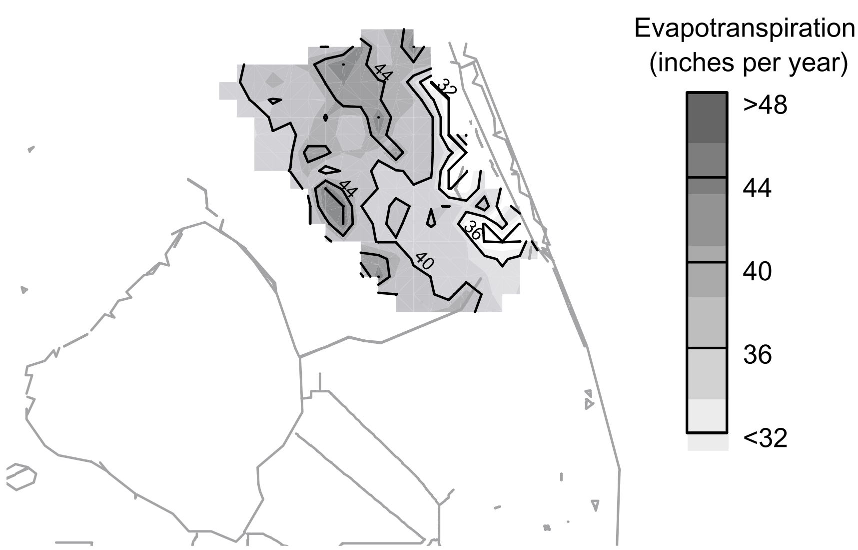
Notes:
- 1965 to 1997 simulation period
- Diamond symbols indicate location of rainfall stations
- Contour line interval = 1.0 inches
- Contour shade interval = 0.5 inches
- Canals and levees included for points of reference

Figure D-6. Average Annual Rainfall within the St. Lucie Watershed

Potential Evapotranspiration

Daily potential evapotranspiration is estimated across the model domain using the computed potential evapotranspiration from two stations: Canal Point and Fort Pierce. Potential evapotranspiration at Canal Point (located along the eastern edge of Lake Okeechobee) is computed using a modified Penman-Monteith Method. Potential evapotranspiration at the Fort Pierce station (located in the northeastern region of the domain) is based on observed pan evaporation data. Potential evapotranspiration is generally higher at Fort Pierce (63.1 inches per year) than Canal Point (57.6 inches per year). Potential evapotranspiration estimates from these two stations are weighted equally to compute the potential evapotranspiration at the individual cells.

"Actual" evapotranspiration is computed in the model, and is based on potential evapotranspiration and a crop coefficient. Crop coefficients combine the effects of vegetation type, seasonality, and water availability. Actual evapotranspiration ranges from less than 20 inches per year in the overdrained cells near the South Fork of the St. Lucie River to more than 48 inches per year in the marsh areas to the southwest (**Figure D-7**).



Notes:
- 1965 to 1997 simulation period
- Contour line interval = 4.0 inches
- Contour shade interval = 2.0 inches
- Canals and levees included for points of reference

Figure D-7. Average Annual Rainfall Map for the St. Lucie Watershed

HYDROLOGIC PROCESSES

Water is distributed within the model domain in response to hydrologic processes. Processes are modeled independently within each time step, with more transient phenomena computed before less transient phenomena. River flow is computed first, followed by overland flow, infiltration, evapotranspiration, and ground water flow. Rainfall is added to the model by increasing surface water depth in each cell at the beginning of a time step. The equations used to represent each of the hydrologic processes will not be presented here. However, the relevant parameters for each of the hydrologic processes are presented.

Infiltration and Evapotranspiration

Vertical movement of water within a cell is simulated by infiltration and evapotranspiration processes. Infiltration rates are uniformly set to a very high level, preventing the formation of perched water tables. Evapotranspiration is a function of potential evapotranspiration, monthly crop coefficient (**Table D-2**), and threshold depths to the water table (**Table D-3**).

Table D-2. Monthly Evapotranspiration Coefficients

Landscape	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Mangrove	.79	.76	.83	.86	.88	.88	.88	.90	.90	.82	.80	.75
Upland Forest	.74	.72	.77	.77	.78	.78	.81	.82	.82	.76	.77	.75
Marsh	.81	.77	.81	.82	.83	.83	.83	.85	.84	.80	.78	.78
Wet Prairie	.72	.70	.72	.74	.74	.74	.74	.75	.75	.73	.73	.70
Wetland Forest	.72	.70	.74	.75	.77	.76	.77	.79	.79	.74	.77	.74

Table D-3. Threshold Water Depths

Landscape	Open Water (feet)	Shallow Root Zone (feet)	Deep Root Zone (feet)
Mangrove	6.5	0.0	4.0
Upland Forest	6.0	4.25	10.0
Marsh	5.0	0.0	4.5
Wet Prairie	4.5	0.0	4.5
Wetland Forest	5.0	0.0	8.0

Overland Flow

The overland flow process simulates the surface water movement between adjacent cells. Manning's equation is used to estimate resistance to flow. Parameters for the Manning's equation are presented in **Table D-4**. The detention depth is the ponding depth below which no overland flow occurs.

Table D-4. Overland Flow Parameters

Landscape	Manning's Coefficient	Manning's Exponent	Detention Depth
Mangrove	0.95	-0.77	0.1
Upland Forest	0.85	0.00	0.1
Marsh	1.15	-0.77	0.1
Wet Prairie	1.20	-0.77	0.1
Wetland Forest	0.16	-0.77	0.1

Ground Water Flow

Ground water flow is simulated by solving for ground water level in a finite difference approximation of flow in unconfined aquifers, using transmissivity values illustrated in **Figure D-4**. A zero gradient ground water boundary condition is imposed by establishing "imaginary" cells outside the model domain, adjacent to each boundary cell. These external cells have the same transmissivity and head values as their model domain counterparts.

River Flow

The river flow process simulates the influence of rivers on water levels in adjacent cells. River cells are identified by the presence of a river segment within the cell (**Figure D-5**). Rivers are modeled as storage volumes, based on river length and width, and depth above a downstream weir that establishes the control elevation (**Table D-5**).

Table D-5. River Specifications

No.	Name	River		Weir Crest		Outlet
		Width (feet)	Slope (feet)	Elevation (feet)	Width (feet)	
1	North Fork Trib1	1,000	4.0	9.0	80	North Fork
2	North Fork	2,000	0.0	3.0	320	St. Lucie Estuary
3	North Fork Trib2	500	0.0	6.0	80	North Fork
4	St. Lucie Trib1	250	0.0	4.0	80	St. Lucie Estuary
5	St. Lucie Estuary	4,000	0.0	2.0	2,000	tide
6	St. Lucie Trib2	500	1.0	3.0	80	St. Lucie Estuary
7	St. Lucie Trib3	750	0.0	4.0	160	St. Lucie Estuary
8	South Fork	500	2.0	3.0	320	St. Lucie Estuary
9	South Fork Trib1	180	2.0	7.0	80	South Fork

RESULTS

The original NSM was developed to provide a better understanding of the predrained hydrology of the Everglades system in South Florida. Planning and restoration initiatives in South Florida have benefited from insights provided by the NSM. The purpose of this study is to use an "NSM-like approach" to gain a better understanding of the natural distribution of flows to the St. Lucie Estuary.

A NSM application includes the computer model itself, hydrologic parameters, static data, and time series data. If the computer model and hydrologic parameters developed for the original NSM (Version 4.5) are accepted as reasonable, then constructing a natural system model for the St. Lucie watershed is a modest effort requiring only static and time series data, which are readily available from previous modeling projects.

The results of the St. Lucie NSM should be viewed as preliminary and for comparison purposes only. The NSM was developed primarily for an Everglades system. Although similar landscapes exist in both model domains, additional work is required to verify that the hydrologic processes and associated parameters adequately represent the St. Lucie watershed.

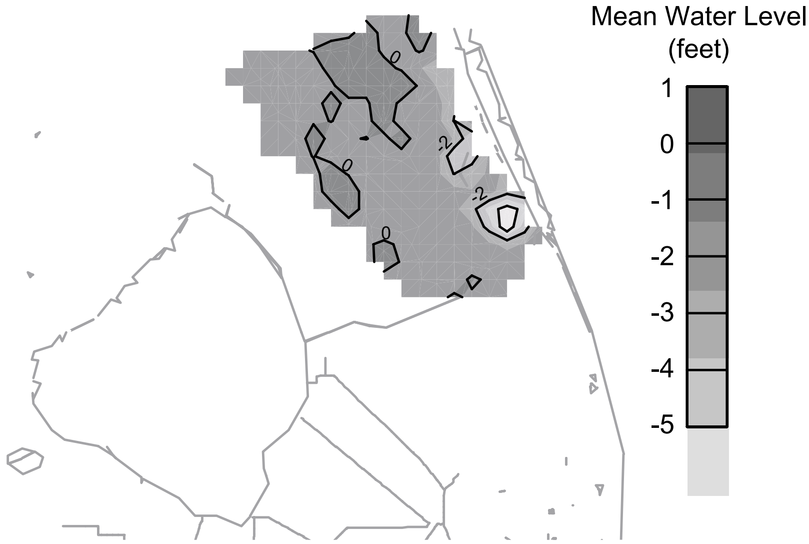
Regional Hydrology

Surface flow in the upper two-thirds of the St. Lucie watershed is primarily directed toward the North Fork of the St. Lucie River (**Figure D-8**). The highest concentration of flow occurs near the western tributary of the North Fork. The lower third of the watershed is generally directed towards the South Fork of the St. Lucie River, with much smaller flow volumes.

Mean water levels in the St. Lucie watershed are generally within 1.0 foot of land surface (**Figure D-9**). Mean water levels are generally below land surface in the forested wetlands and above land surface in marshes and wet prairies (**Figure D-2**).

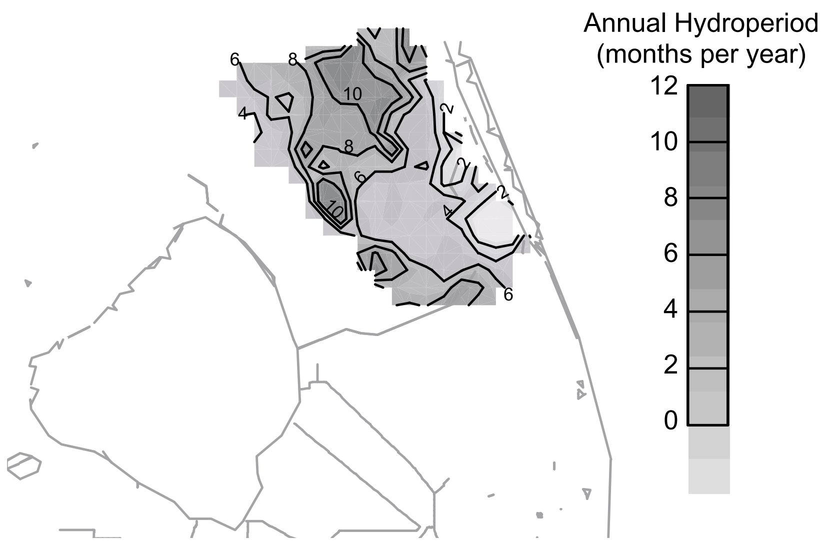
The duration of inundation can be assessed using hydroperiod maps, where hydroperiod is defined as the number of days per calendar year in which the water level in a cell is above land surface. The deep water areas in the wet prairies tend to have longer hydroperiods, ranging between 8 and 11 months (**Figure D-10**). Hydroperiods in western to central forested wetlands are shorter, generally ranging between 4 and 7 months. Hydroperiods in areas drained by the St. Lucie River and its tributaries are very short, generally less than 4 months.

Figure D-8. Surface Flow Vector Map for the St. Lucie Watershed



Notes:
-1965 to 1997 simulation period
- Water levels referenced to land surface elevation
- Contour line interval = 2.0 feet
- Contour shade interval = 1.0 feet
- Canals and levees included for points of reference

Figure D-9. Mean Water Level Map for the St. Lucie Watershed



Notes:
-1965 to 1997 simulation period
- Hydroperiod = number of days of inudation per calendar year
- Contour line interval = 2 months
- Contour shade interval = 1 month
- Canals and levees included for points of reference

Figure D-10. Median Annual Hydroperiod Map for the St. Lucie Watershed

Local Hydrology

The depth of water in adjacent cells may differ because of differences in relative topography, vegetation, and net rainfall. These localized effects can be minimized by computing the average depth of water for groupings of adjacent cells. Blocks of at least three-by-three cells were identified in the wet prairie, northeastern forested wetland, and southwestern forested wetland landscapes. Water depth in these blocks is the arithmetic average of the water depth simulated in the individual cells. Daily water depths for each block are sorted by calendar day, ranked in ascending order, and presented as percentiles in **Figure D-11**. These percentiles summarize the daily distribution of water depths across the 33-year simulation period. For example, the 50th percentile (or median) for January 1 is the water depth wherein 50 percent of the years report water levels less than this value. The median value is computed for each day of the year and the results are displayed as the median trace. Traces for the tenth and ninetieth percentiles are computed in the same manner.

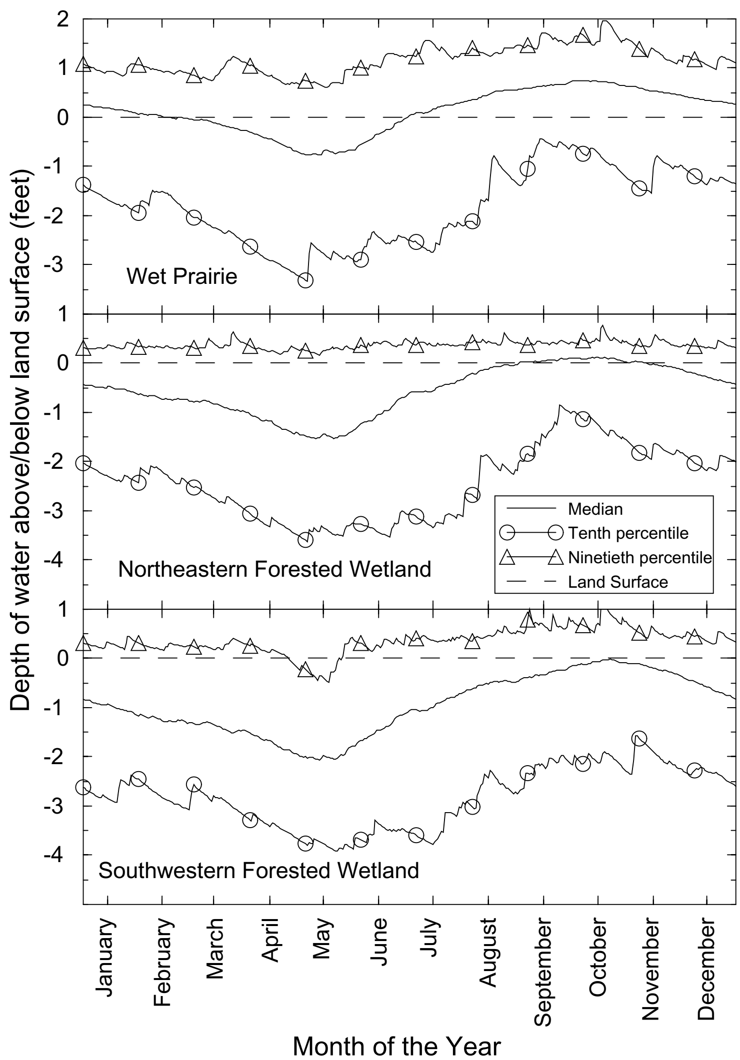


Figure D-11. Water Level Percentiles for the St. Lucie Watershed

Water levels in each of the landscapes can vary widely throughout the year, dropping as low as 4 feet below land surface in the forested wetlands to as high as 2 feet above land surface in the wet prairie. As previously noted, the wet prairies tend to be the wettest of the landscapes. The median water level trace is above land surface for all but four months near the end of the dry season.

St. Lucie Estuary Inflow

The St. Lucie River system is represented in the model by five tributaries discharging into the St. Lucie Estuary, which in turn discharges to tide. Direct flow into the St. Lucie Estuary is estimated by summing the inflows from the North Fork, South Fork, and three smaller tributaries designated as Trib1, Trib2, and Trib3 (**Figure D-5**). The distribution of monthly flow is illustrated in **Figure D-12**. Monthly inflow into the St. Lucie Estuary (not including direct rainfall and evaporation on the estuary) ranges from 286 acre-feet per month to 365,000 acre-feet per month, with 90 percent of the inflows between 2,000 and 130,000 acre-feet per month.

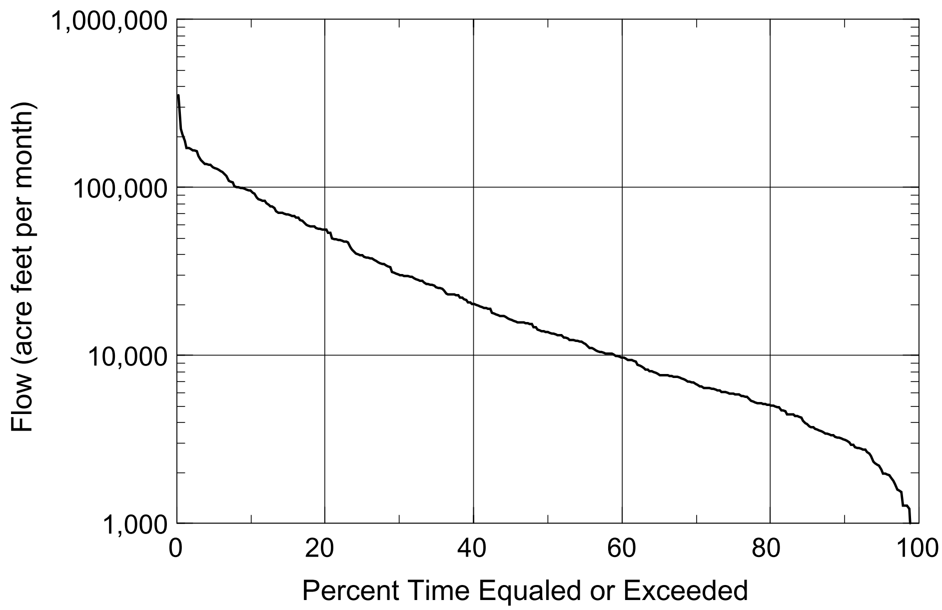


Figure D-12. Distribution of Flow into the St. Lucie Estuary

REFERENCES

Davis, J.H., Jr. 1943. *The Natural Features of Southern Florida*. Bulletin 25, Florida Geological Survey, Tallahassee, FL.

SFWMD. 1999. *A Primer to the South Florida Water Management Model, Version 3.5*. South Florida Water Management District, West Palm Beach, FL.

Fennema, R.J., C.J. Neidrauer, R.A. Johnson, T.K. MacVicar, and W.A. Perkins. 1994. A computer model to simulate natural everglades hydrology. In: Davis, S.M., and J.C. Ogden (eds), *Everglades: the Ecosystem and its Restoration*, St. Lucie Press, Delray Beach, FL, pages 249-289.

Sculley, S.P. 1986. *Frequency Analysis of South Florida Water Management District Rainfall*. Technical Publication 86-6, South Florida Water Management District, West Palm Beach, Florida.

Van Zee, R.J. 1999. *Natural System Model Documentation, Version 4.5.* South Florida Water Management District, West Palm Beach, FL.

Zahina, J.G., K. Liudahl, T. Liebermann, K. Saari, J. Krenz, and V. Mullen. 2001. *Soil Classification Database: Categorization of County Soil Survey Data within the SFWMD including Natural Soils Landscape Positions*. Technical Publication WS-06, South Florida Water Management District, West Palm Beach, FL.

APPENDIX E
PREDRAINAGE LANDSCAPE ECOLOGY AND HYDROLOGY OF THE ST. LUCIE WATERSHED ESTIMATED FROM HISTORICAL SOURCES

Christopher McVoy, SFWMD

INTRODUCTION

This report was researched and written in response to a request for information from Dan Haunert of the Upper East Coast Division, South Florida Water Management District. The objective of this time-limited study was to develop a sense of predrainage hydrology of the St. Lucie River watershed, based on an understanding of the area's predrainage landscape ecology. Source materials included satellite imagery, United States Government Land Office township surveys from the 1850s, field notes from the same township surveys, knowledge of drainage history, maps of the present drainage system, United States Geological Survey (USGS) topographical quadrant (topo quad) maps, maps from the 1940s of vegetation and soils, and knowledge of remaining "natural" areas. Contour maps of elevation at 1-foot resolution would have been very useful, but were not available. The approach is deductive, using multiple sources of landscape information to piece together a predrainage picture consistent with all available information.

The following questions were to be addressed:

- What spatial patterns were present within the watershed?
- What directions might water have drained under natural conditions?
- What were the relative contributions of the North and South Forks of the St. Lucie River?

Ideally, these questions would be answered from direct observations of predrainage hydrology, such as water depths during the course of the year, durations of above ground water, and observed flow directions. As it was recognized that such direct observations were unlikely to be available, at least in sufficient numbers to cover the whole watershed, indirect approaches based on landscape ecological knowledge were necessary. Predrainage vegetation and soils, when known, can be useful indicators of predrainage hydrology, particularly if additional topographical information is available to position the vegetation types and soils within the landscape.

It is important to recognize from that outset that, by all indications, the St. Lucie River watershed has been extensively and intensively influenced by drainage. Almost every square mile is traversed by numerous drainage canals and ditches (**Figure E-1**). It is also important to recognize that historical information (e.g., Randolph et al., 1919), as well as the accessibility of the landscape, suggest that significant drainage was in place

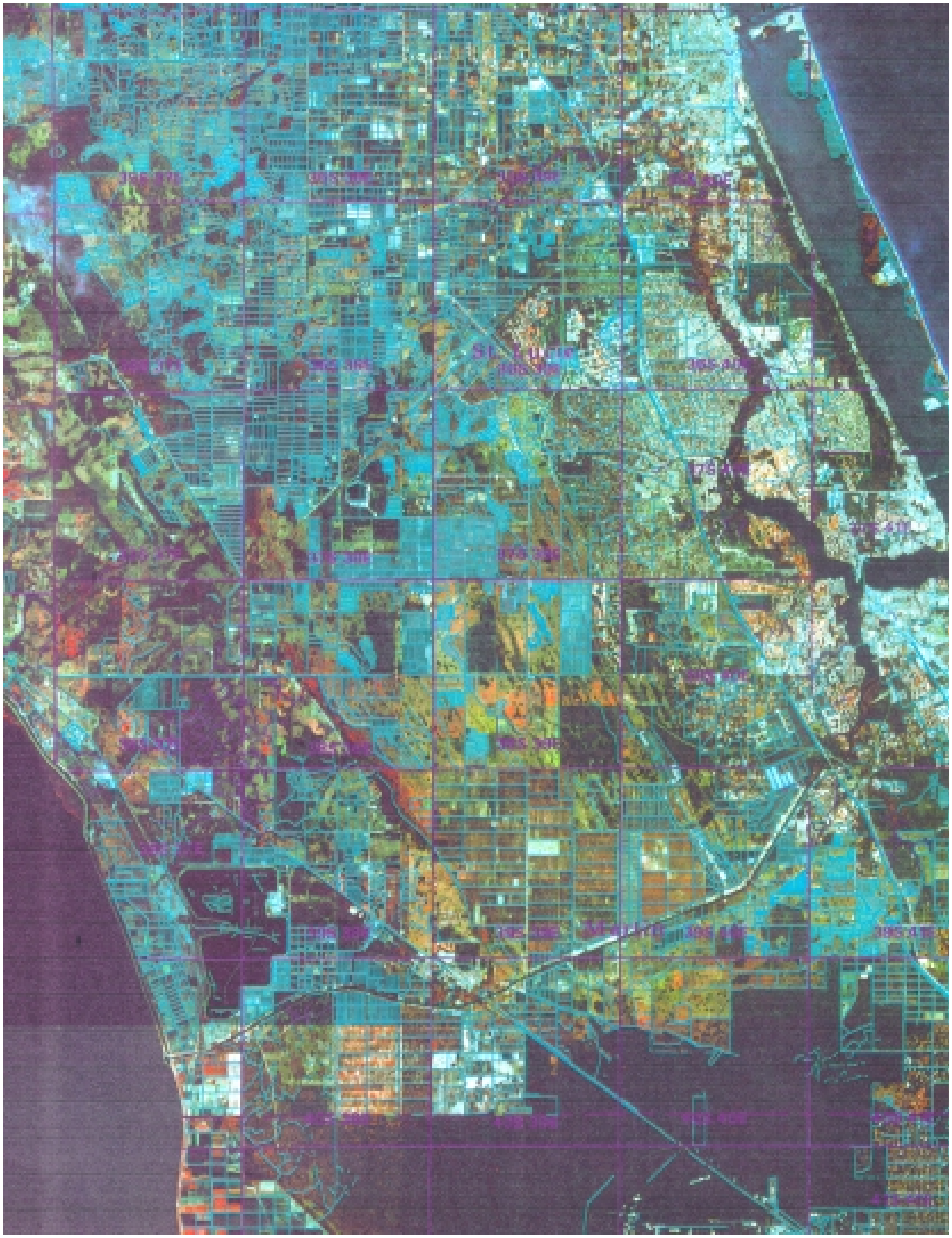


Figure E-1. Satellite Image of the Northwestern Portion of the St. Lucie River Watershed with the Current Canal System and the Township-Range Grid well before the 1940s. Substantial and significant landscape change almost certainly accompanied this drainage. Peat soils in this area originally accumulated in low spots in the underlying sand due to prevention of oxidation by standing water present during much of the year. Once drainage had lowered water tables below the land surface, complete loss of the peat could easily have occurred within a few decades (Stephens and Johnson, 1951), as these soils were generally not more than a few feet deep.

The ephemeral nature of shallow peat soils in South Florida, once drainage is initiated, has important implications for understanding predrainage landscape ecology and hydrology. The flatness of the area, combined with the quantities and timing of rainfall that originally kept the water table close to ground surface, means that variations of only a few feet create the difference between upland pine or oak-cabbage hammock areas on a sand or loamy sand substrate and wetland swamps or sawgrass ponds on a peat substrate. If drainage causes the low lying peat soils to completely oxidize away, the newly exposed underlying sand can come to resemble the sandy substrate of the original (predrainage) upland areas. Wetland and upland areas, once easily distinguishable, can blur, with upland vegetation starting to appear throughout. This is not surprising; in a sense it is the intended objective of drainage – to transform "swampland" into habitable or cultivatable "uplands."

The significance of the ephemeral nature of organic (peat) soils to correctly understanding predrainage ecology and hydrology is that soil mapping carried out after drainage has begun cannot be assumed to reliably indicate the presence of predrainage wetlands. At best, postdrainage maps will underestimate the area of wetlands. At worst they can misleadingly indicate complete absence of wetlands if all peat has been lost.

As a result, vegetation maps from the 1940s (e.g., Davis, 1943), soil maps from the 1940s (Jones et al*.,* 1948), present day soil maps, and present day satellite images all are inherently unreliable indicators of the predrainage landscape patterns within the St. Lucie River watershed. These sources can provide very useful leads and suggestions of predrainage conditions, but the information must be carefully interpreted, using predrainage information that includes spatial detail.

Cursory inspection of a number of Government Land Office township survey maps (**Figure E-2**) from within the watershed indicated that most of the area originally formed a mosaic, with multiple elements present within a square mile. Open polygons are "Ponds," probably open water ponds, in a few cases labelled in the field notes as "Saw Grass Ponds." Current topographic maps (**Figure E-3**), satellite imagery, and the Davis (1943) vegetation map (**Figure E-4**) tend to confirm the presence of a mosaic. The presence of wetlands in **Figure E-3** matches those drawn 130 years earlier on the township plat (**Figure E-2**) along the surveyed section lines. However, the topographical map (**Figure E-3**) shows additional wetland extent within the section interiors, as well as showing the northwest to the southeast orientation of the wetlands. Note the coincidence of a drainage ditch network in Sections 29 and 32 of **Figure E-3** with an area marked "Savanna" on the township plat (**Figure E-2**).

In light of the mosaic nature of the vegetation, the original questions were necessarily modified as follows:

- What were the main two or three elements composing the predrainage mosaic?
- Was the mosaic random in orientation, or did elements form an organized pattern?
- Was the mosaic different in different parts of the watershed?

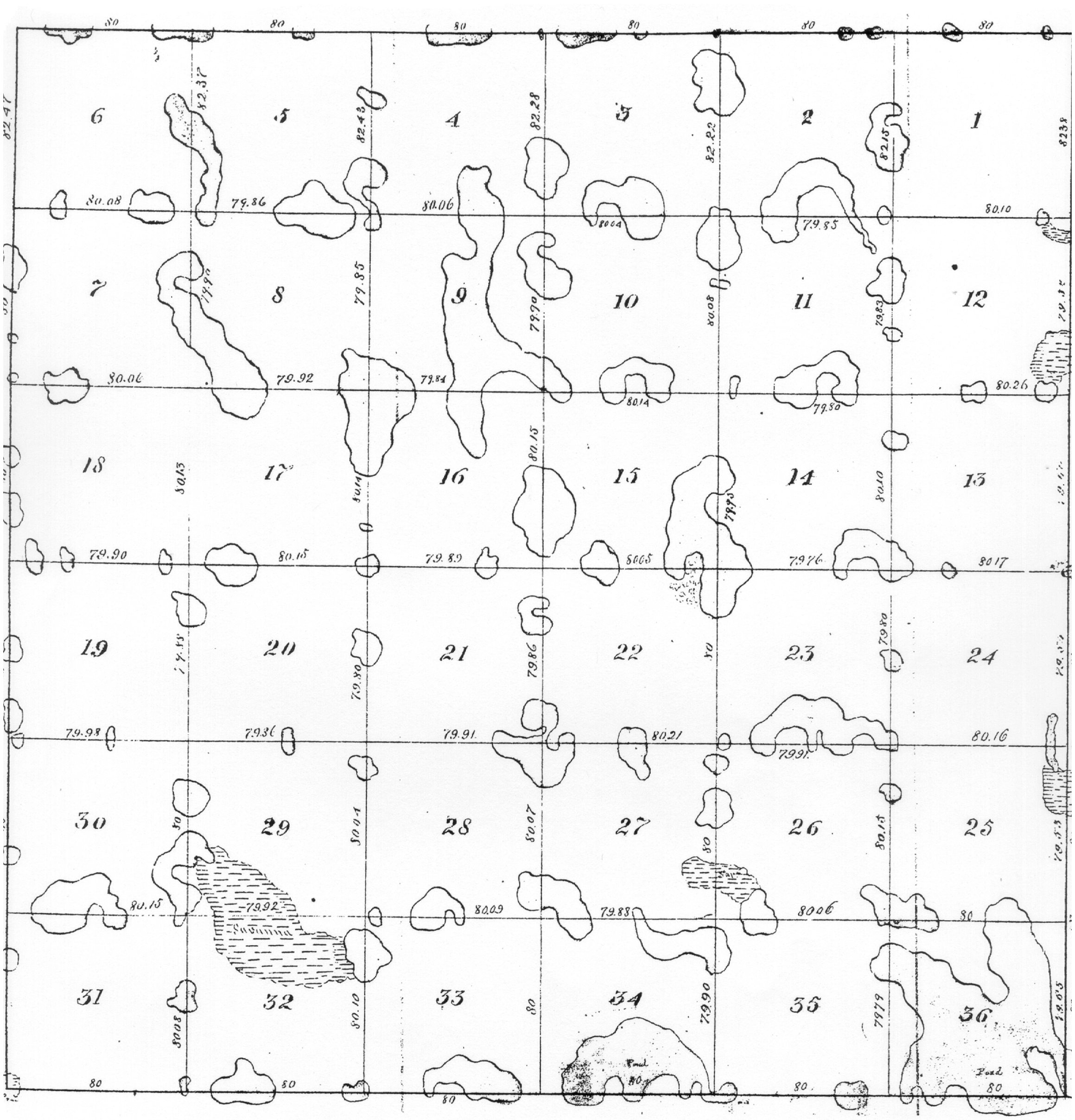


Figure E-2. Sample Township Plat Map of Township 38 South, Range 39 East, Surveyed by M.A. Williams in May and June of 1853

Figure E-3. USGS Topographical Quadrant Map of Township 38 South, Range 39 East, Photo Revised in 1983

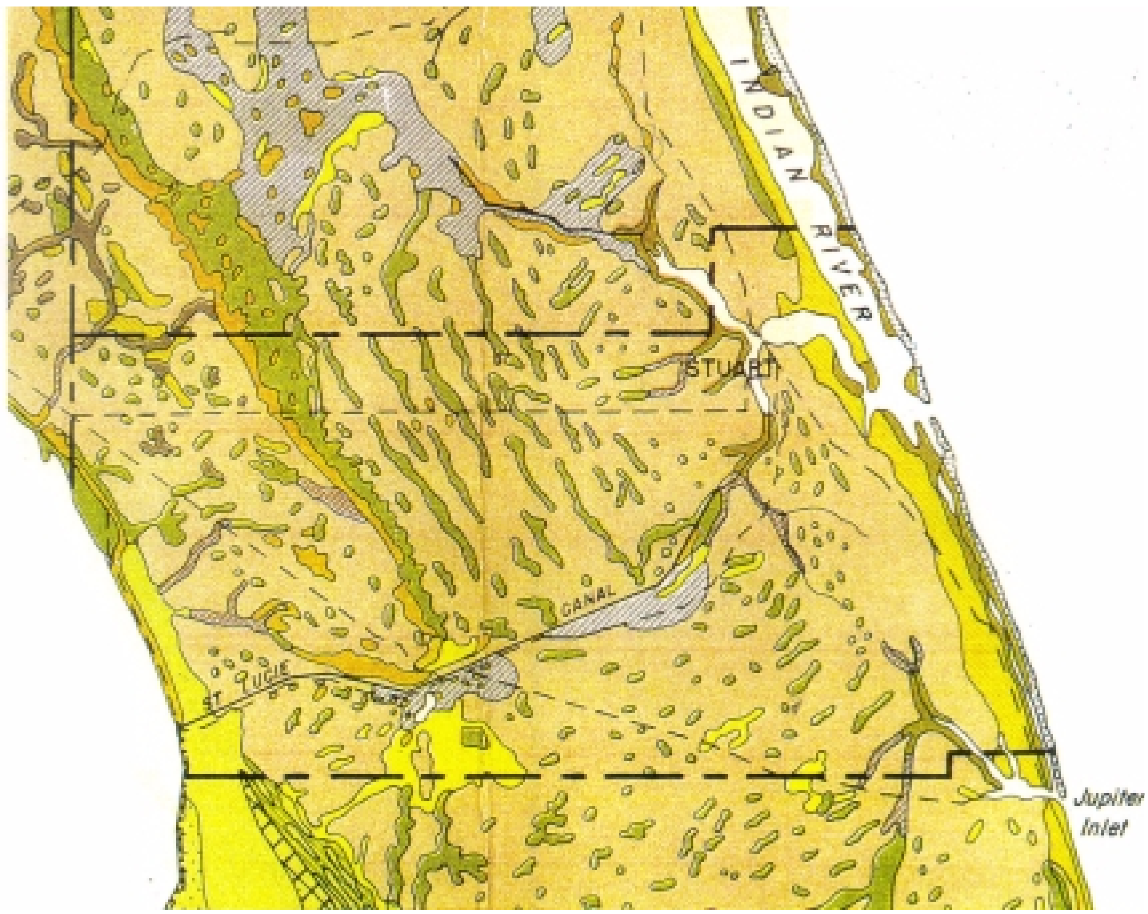


Figure E-4. St. Lucie River Watershed Portion of the *Vegetation Map of Southern Florida* (Davis, 1943)

METHODS

This brief reconnaissance study was initiated by examination of a satellite image overlain with a township range grid (**Figure E-5**). By inspection, four townships ranging from north to south within the watershed were selected, based on the remaining presence of original mosaic pattern (townships outlined in red on **Figure E-5**). The four townships were also selected for their alignment with the prevailing northwest to southeast pattern, possibly related to relict sand dunes. It was necessary to include an additional southern township (Township 40, Range 38), as field notes were not available for Township 40, Range 40.

Each of these five townships (36 square miles each) was "sectioned" between 1853 and 1855. Sectioning involves walking the boundaries of each square mile and measuring and describing vegetation and water bodies. Three different deputy surveyors were involved, all under State Surveyor General John Westcott. I examined each of the five plat maps (scale 2 inches = 1 mile), and used the section boundaries to compare them with current USGS topo quad maps (scale 2 5/8 inches = 1 mile) (Compare for example **Figures E-2** and **E-3**).

The field notes available for four of the five townships were then read (84 linear miles for each township) and compared with the plats to develop a sense of the mosaic elements present within each township. Three aspects associated with each mile were examined: 1) the transitions between different elements (e.g., "33.00 [chains] exit Pine, enter Saw Grass Pond"), 2) the species of witness trees noted to locate the section and quarter section marker posts, and 3) the overall description included at the end of each mile (e.g., "3rd Rate Pine[, Saw] Palm[etto] & Ponds"). Given the time limitation, the examinations of the field notes were necessarily qualitative, rather than quantitative.

A separate, second effort examined township plats located in the Allapattah Flats area along the eastern foot of the northwest-southeast ridge forming the western boundary of the watershed. This area was originally called Halpatta Swamp (Williams, 1853) and Alpatiokee Swamp (Florida Surveyor General's Office, 1853). Comparison of township maps with satellite imagery (**Figure E-5**) and with the Davis (1943) vegetation map (**Figure E-4**) suggested that much of the original extent and character of the Halpatta Swamp area had already been lost or altered prior to 1943, leading to an underestimate of this area.

A third effort compared township plat maps in the headwater areas for the North and South Forks of the St. Lucie River.

Written records of the area presently known to the author were examined. Considerably more narrative material is almost certainly available, but it could not be researched within the short time frame of this study.

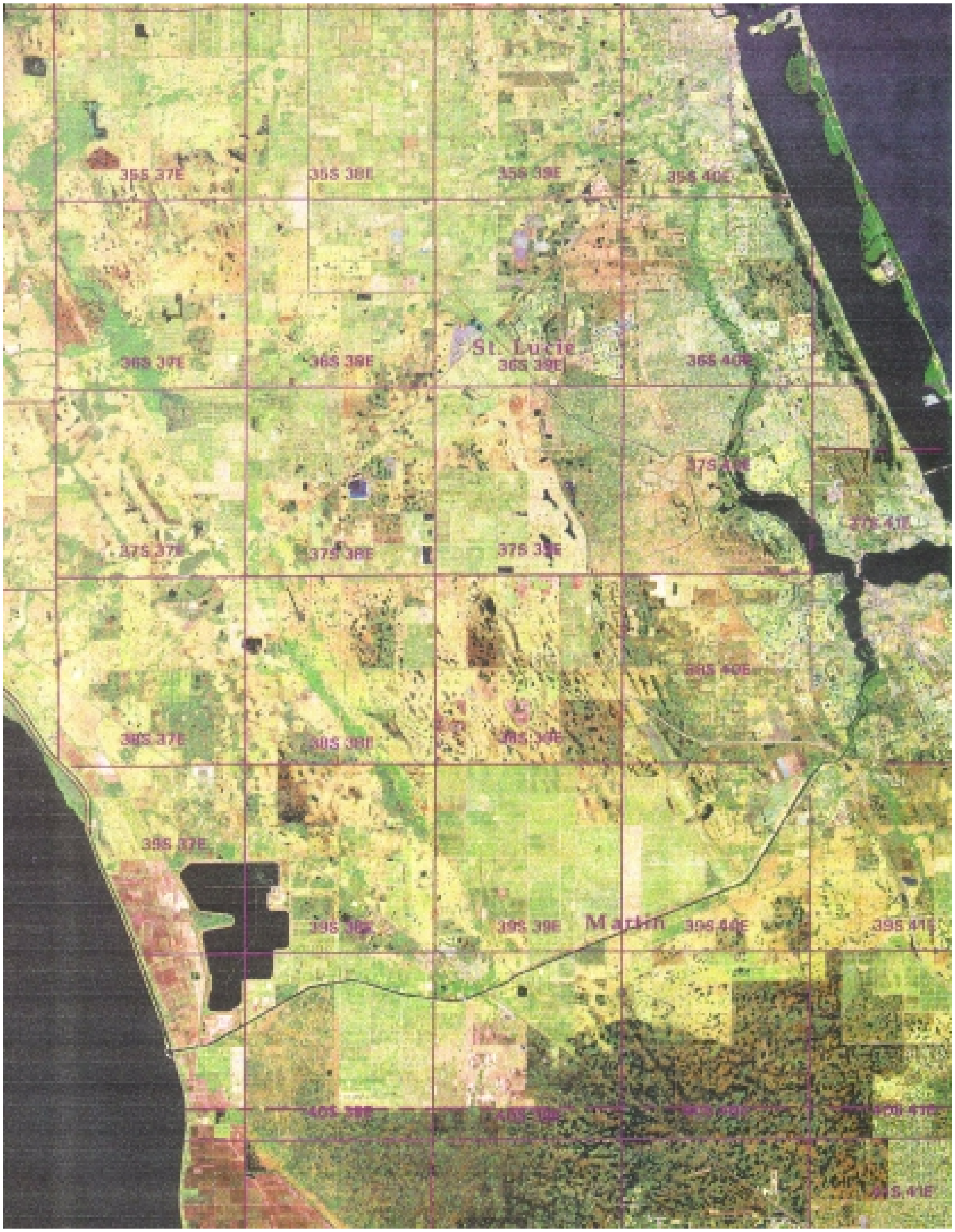


Figure E-5. Satellite Image of the Northwestern Portion of the St. Lucie River Watershed, with Township Range Grid (note relation of land use to the township range grid)

RESULTS

General

A rough map compiled by the Surveyor General's Office in St. Augustine (Florida Surveyor General's Office, 1853) shows both the South and North Fork of the St. Lucie River draining from an approximately 400-square mile area labelled the "Alpatiokee Swamp" (**Figure E-6**). Plat maps and field notes for several of the townships mention a "Halpatta Swamp" and an "Alpatiokee Swamp." Further research would be needed to determine if these were alternate names for the same natural feature, or two separate features. As has often been the case in postdrainage South Florida, place names have changed as the landscape becomes drier under drainage. The current label "Allapattah Flats" is a postdrainage name certainly derived from Halpatta or Alpatiokee Swamp, but the area is no longer wet enough to be referred to as a swamp. Much of it is now cultivated as citrus groves.

A map compiled in 1913 by the Florida Geological Survey on a base map by the USGS (Matson and Sanford, 1913) labels the South Fork of the St. Lucie River as "Halpatiokee R.," suggesting a link with a Halpatta or Alpatiokee Swamp(s).

In a letter to Dr. V. M. Conway, the Surveyor General of Florida, George MacKay, a United States Deputy Surveyor of many townships in southern Florida, wrote the following regarding what appears to be the St. Lucie River watershed:

> The country is generally poor land. Immediately on the Indian River Lagoon, it is low oak scrub & on my west line, it is open pine prairie, and saw grass savanna. Small pine scrubs. The savannas are the best land, tho' in the rainy season of the year they are covered with water. The --?-- --?-- entirely dry, and present a pleasing view. (MacKay, 1846)

Mackay mentions the "sawgrass savannas" as the "best land" probably to contrast them from the common "3rd Rate Pine Lands" of Florida, found on sand with little native fertility. "Best" very likely refers to the presence of a top layer of organic peat soil, accumulated from wetland sawgrass growth. If this is the case, it would indicate that hydroperiods were probably 8 to 10 months of the year, such that the rate of organic matter accumulation slightly exceeded the rate of oxidative loss during the few months when standing water was absent. These also appear to be the optimal conditions for sawgrass: presence of peat soil, and water throughout most, but not all of the year.

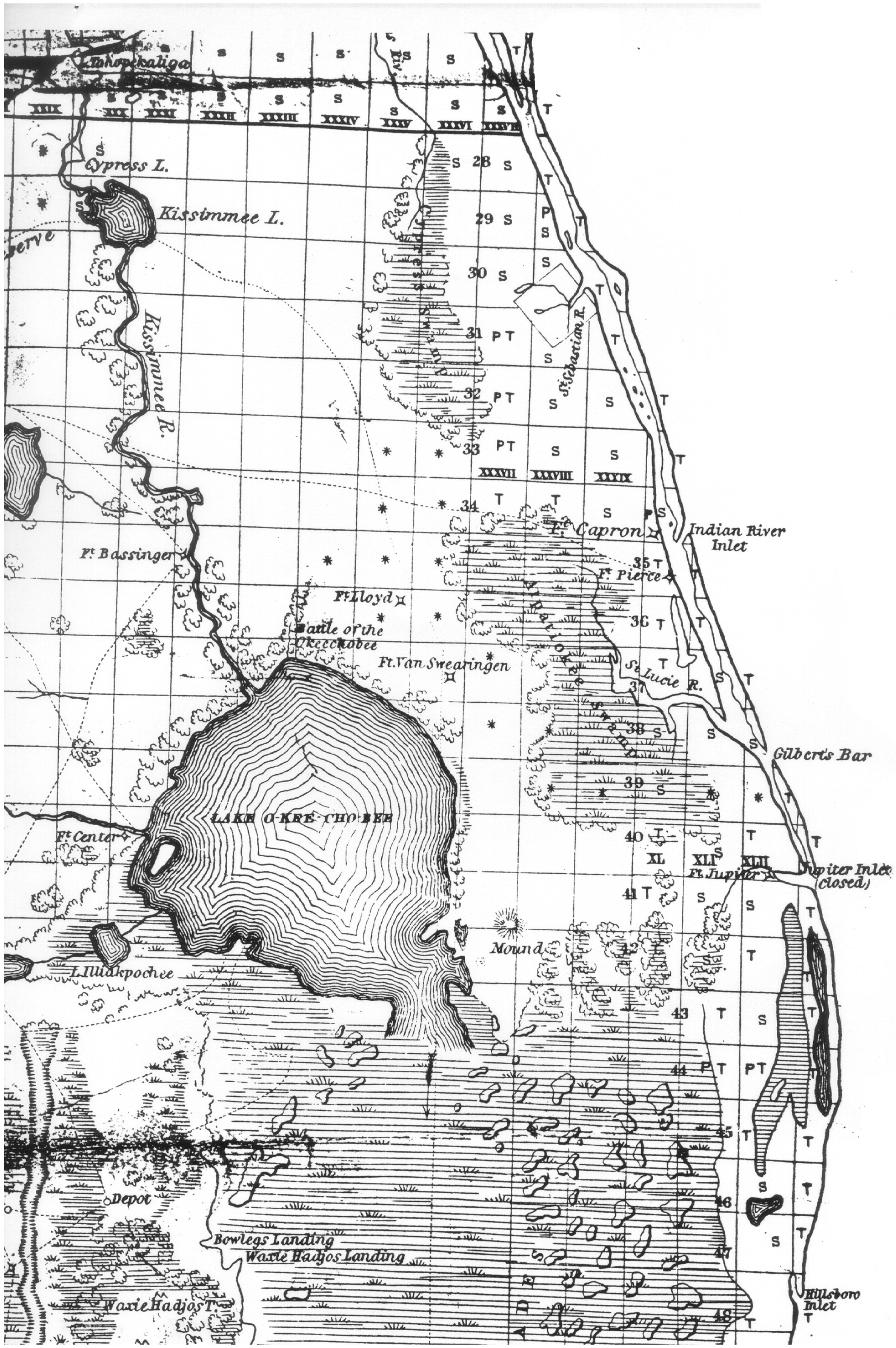


Figure E-6. United States Bureau of Topographical Engineers' Map of Southern Florida in 1853 Showing "Alpatiokee Swamp" as the Headwaters of the North and South Forks of the St. Lucie River.

In 1882, the Trustees of the Internal Improvement Fund, for the State of Florida, employed Silas L. Niblack as an agent to examine the following:

> The lands granted to the State of Florida as Swamp [and Overflowed] lands under the Act of September 28th, 1850" … [such examination being] "for the purpose of ascertaining the general character of the Swamp lands … with respect to their ability to overflow … and what proportion of said lands are already high and dry enough for cultivation… (Nilback, 1882)

Niblack's report of June 1882 states that "the balance of the land in Dade County would come within the terms of your drainage contract" (Niblack, 1882). At that time, Dade County extended much farther north than at present, including the St. Lucie River watershed. "Balance" refers to all of Dade County except the high ground near the New and Miami Rivers. Therefore, Niblack is stating that the whole St. Lucie River watershed was in fact subject to overflow.

Even in adjoining, higher elevation, pinelands, dry ground was the exception to the rule:

> Within this limit there is in the neighborhood of Fort Drum [Township 34, Range 35] a pine ridge about five miles in length and 1/2 to 3/4 mile in width, that might be, with light drainage cultivated; there is also near Taylor Creek a small ridge of Pine land that during a dry season might be cultivated, but subject to overflow in a wet season. (Niblack, 1882)

Niblack concluded by writing the following:

> I give it as my opinion and views resulting from examination and information received, [that] it is not advisable to have a … survey made of the State lands within said limits and a list prepared designating those not subject to overflow… [because] … I am satisfied the quantity of land <u>not</u> now subject to overflow, would be so small it would not pay the State the expense of examination and survey. (underline added; Niblack, 1882)

In 1919, two engineering firms, Isham Randolph and Company, consulting engineers, and Cunningham and Hallowes, chief engineers, issued a report and plan of reclamation for the North St. Lucie River Drainage District (Randolph et al., 1919). This drainage district (Townships 35 and 36; Ranges 38, 39, and 40) lies in the northeastern portion of the St. Lucie River watershed (**Figure E-5**). We quote extensively from their report, as it gives a good sense of the landscape and landscape elements mapped by the township surveyors. Note, however, that inspections of township maps from throughout the St. Lucie River watershed indicate that the North St. Lucie Drainage District portion included a higher proportion of "Prairie" landscape than the rest of the watershed:

> The lands within the District may generally be described as flat, although elevations vary from fourteen to twenty-four feet above sea level. The highest lands are the pine woods which lie principally in the eastern half

> of the District. The prairie lands which are located mainly in the western portion of the district are flat, but there is a general slope from all portions of the District to Ten Mile Creek and Five Mile Creek and to the North Fork of the St. Lucie River, which is formed by the confluence of the first two named streams. These streams together afford the existing natural drainage outlets for the lands within the District as well as for a large body of prairie land lying further west. (Randolph et al., 1919)

The pine woods referred to on high ground in the eastern portion were probably associated with the Atlantic Coastal Ridge. This is in contrast to much of the rest of the St. Lucie River watershed, where pines formed part of a mosaic landscape of "3rd Rate Pine and Ponds." The statement that Ten and Five Mile Creeks are the natural drainage outlets for the North district and even for the prairie lands further west is no doubt true. However, further research would be required to determine whether water reached the creeks primarily as surface water or as (shallow?) ground water flow. Three points suggest an important contribution of ground water: 1) a later statement by Randolph et al. (1919) concerning the "lack of natural drainage" in the prairies; 2) apparent absence, at least in some areas, of a clear pattern of directionally connected surface wetlands; and 3) the presence of a soil layer of lower hydraulic conductivity several feet below the upper, more conductive sand horizon:

> SOIL AND VEGETATION: ... The soil of the District consists of Hammock, Muck, Prairie and Pine lands. Approximately ninety percent of the lands are underlaid with a marl or clay subsoil, at a depth of from one to four feet. Probably three percent of the lands are underlaid with hardpan, and the balance has a subsoil of sand. (Randolph et al., 1919)

Modern soil surveys should be consulted to confirm the widespread presence of a marl or clay subsoil. If present, such subsoil would provide high water holding capacity as well as a restriction to rapid downward drainage of water, tending to create consistent base flow from the watershed, rather than the more transient, "spikier" ground water discharges associated with a completely sandy profile.

> PRAIRIE: The District includes 40,418 [out of 75,000] acres of prairie land. These are lands, usually very level, which through lack of natural drainage in the past have been so wet as to prevent the growth of trees. The existing vegetation is confined to native grasses, which make a luxuriant growth where water does not stand for too long a period. These lands have a general top soil of heavy sandy loam, underlaid with clay or marl. They respond readily to drainage, and private operations on limited tracts have indicated them as well adapted for groves or general crop production. The fact that no clearing [of trees] is required in developing these lands is a consideration in determining their present and future value. (Randolph et al., 1919)

As sawgrass is not specifically mentioned, it is not clear to what extent this corresponds to the "saw grass savannas" mentioned by MacKay (1846), or to more of a wet prairie environment of some combination of spike rush (*Eleocharis*), beak rush (*Rhynchospora*), and maiden cane (*Panicum hemitomon*). "Luxuriant growth" is suggestive, but not conclusive, of saw grass. Reference to absence of vegetation where water "stands for too long a period" probably refers to the open water ponds depicted on all township plat maps of the St. Lucie River watershed that I examined.

In some parts of the prairie landscape, depressions were apparently deep enough to allow accumulation of significant peat soil deposits:

> In isolated tracts where local depressions in the prairie lands have brought about conditions favorable to a rank growth of [water] lilies, Maiden cane and other water grasses, a cover of well rotted muck varying from a few inches to six feet in depth is found. As at least the upper portion of the muck is ordinarily dry for a considerable part of each year, oxidation and decomposition of the vegetable matter has proceeded to an advanced degree, and the result is a soil which may be made highly producive by proper handling. (Randolph et al., 1919)

The description of open ponds covering 10 percent of the North St. Lucie River Drainage District suggests sand-bottomed areas with sparse vegetation, perhaps 8 to 10 months of standing water, and maximum depths of 1 to 2 feet of water:

> OPEN PONDS: 7,270 [out of 75,000] acres of land in the District consists of open ponds. These lands similar in general nature to the prairie lands, but which are of such elevation as to be covered with a shallow depth of water for the greater portion of the year. For this reason the growth of vegetation in the past has been light and the top soil is of correspondingly poorer nature. These ponds are all of such elevation as to permit complete drainage under the Proposed Plan of Recommendation. (Randolph et al., 1919)

Absence of ponds on satellite imagery in areas where they had originally been shown on township maps suggests that Randolph et al. (1919) predicted correctly. Sufficient man-made drainage was achieved to lower the water table below even the bottom of the pond elevations. Water tables were apparently lowered enough that both higher ground and former ponds could be farmed equally. The disappearance of most predrainage ponds was probably not caused by drainage alone. Land leveling may have been partially responsible for this drainage (Konya, 2000).

Township Maps

This section focuses on detailed examination of a series of five townships extending northwest to southeast through the St. Lucie River watershed. All township plats examined showed evidence of the mosaic nature of this region, mostly “Ponds” within a matrix of less wetland vegetation. Some plat maps also showed regional features, such as the Halpatta Swamp (Allapattah Flats), consisting of “impracticable” sawgrass and bordering “Bay Galls,” “Swamp,” or “Savanna”. Interestingly, the ponds were usually drawn as features about 1/8 to 1/4 of a mile across, and curiously lined up in north-south and east-west rows. Probability aside, the satellite imagery and the topographic maps clearly indicate that these neat rows do not accurately depict the original landscape. Detailed comparison of individual square mile sections between the township plats and the topo quad maps shows that the township surveyors tended to draw disconnected, circular ponds centered on the section lines (**Figure E-2**; see for example Sections 7 and 8), whereas in actuality the ponds had more complex shapes (**Figure E-3**). Actual ponds often extend, and presumably extended, northwest to southeast, and crossed two or more section lines. As the surveyors only walked the borders of the mile square sections, and did not have the benefit of aerial views of the landscape, they often incorrectly drew larger, rambling ponds as a series of circular, independent ponds, not realizing that they were in fact connected. From this, it is apparent that the township plats are not a reliable way to estimate the fraction of the mosaic occupied by ponds.

Evaluation of the landscape fraction occupied by ponds prior to drainage is best done using the topographical maps and/or the satellite imagery. Note, however, that comparison of two different satellite images, taken at different times, suggested that the size of these ponds can change significantly as water levels rise and fall.

Water depths and the duration of standing water (hydroperiod) were not recorded in the field notes for these townships. One mention of stream flow direction was found. An important limitation of this analysis of the watershed and these township survey results is the author’s lack of having explored the area on foot.

Although streams were generally drawn on township maps, only one was found connecting ponds within the St. Lucie River watershed. However, many streams connecting ponds are shown on township plats from within the high ridge area to the west of the watershed. Shapes of the ponds, when examined jointly on topographical maps as well as the township plats, generally did not suggest strong interpond connections, although this varied somewhat between townships. Overall, the impression was one of a landscape drained more by slow ground water flow than by surface runoff. Ten Mile Creek, contrary to expectations, was found not to extend much further on the plat maps than it currently does on topographic maps.

Township 36, Range 37

The southwestern corner of this township bordered the western ridge, and included what appeared to be a northern portion of the Halpatta Swamp (Allapattah Flats) area. This portion of the Hallapata Swamp included three separate areas of “Hammock” in a northwest-southeast line, as well as some “Swamp,” “Bay Swamp,” and “Low Prairie” areas. Interestingly, this same western area now appears to have become wetter. It is possibly used as a local detention basin. The topographical maps currently show it as cypress swamp, rather than as hammocks. The majority of the township was labelled “Prairie.” It is not exactly clear what “Prairie” refers to, but it appears to have included some pine, saw palmetto, and cabbage palm. Pits and mounds were used to mark some section corners, apparently because no witness trees were available. Sawgrass ponds were scattered throughout the prairie area. The Jones Hammock and North of Bluefield (Okeechobee 1 SE) USGS topo quad maps show a considerable number of isolated wetlands (possibly former sawgrass ponds), as well as a number of networks of drainage ditches. Elevations in the township ranged from 25 to 30 feet above sea level. Landscape categories reported in the Government Land Office field notes for Township 36, Range 37 are presented in **Table E-1**.

Table E-1. Landscape Categories Reported in the Government Land Office Field Notes for Township 36, Range 37[a]

Landscape Category	Witness Trees	Comments
3rd Rate Prairie 3rd Rate Pine & Palm[etto] Prairie	Pits, cabbage [palm], pine	Matrix over most of township; includes “Saw Grass Ponds” and “Pine Islands”
Saw Grass Ponds	--	More scattered wetlands (“Ponds”?) shown on USGS topo quad than on township plat – significant?
Pine Islands Pine Lands	Pine	Considered as distinct inclusions within “Prairie”; matches well with forested areas on topo quad map
1st Rate Hammock	Oaks, cabbage palms, ash (1)	Occurred as northern extension of Hallapata Swamp, northwest-southeast; probably rich soils
Swamp	Cypress	Two smaller areas; west side of township
Bay Swamp Bay Gall	Bay	Small; west side; with “Low Prairie” and “Swamp”
Saw Grass Marsh	-	One small area only

a. Surveyed by C.F. Hopkins in July 1853

Township 37, Range 38

The western half of Township 37, Range 38 was all “Saw Grass” and “Savanna”, which are part of the Hallapata Swamp features. The eastern half was a matrix of “3rd Rate Pine” with inclusions of numerous “Ponds.” As one pond was specifically labelled “Saw Grass Pond,” it is assumed that the numerous others labelled only “Pond” were either too deep for sawgrass or too shallow to accumulate enough peat for sawgrass. More pine and fewer cabbage palms appear to occur in this township than in Township 36, Range 37. Less developed parts of this township show wetlands throughout on USGS topo quad maps Bluefield (Okeechobee 4 NE) and North of Bluefield (Okeechobee 1 SE); topo quad maps give a wetter impression than the survey notes. The large sawgrass area in Sections 31, 32, 30, 29, and 19 (Hallapata Swamp/Allapattah Flats) is visible on the topo quad maps and includes some forested area. Elevations in the eastern half of the township, which were pineland, were 25 to 28 feet above sea level, mostly around 26 feet. Three “Flowing Wells” are marked in the eastern half of the area. Landscape categories reported in the Government Land Office field notes for Township 37, Range 38 are presented in **Table E-2**.

Table E-2. Landscape Categories Reported in the Government Land Office Field Notes for Township 37, Range 38[a]

Landscape Category	Witness Trees	Comments
3rd Rate Pine & Ponds 3rd Rate Pine & Rough Palm[etto] (1)	Many pines, a few cabbage palms	Matrix over eastern half of township; includes “Ponds”
Ponds or Saw Grass Pond (1 only)	--	Vegetation unclear, but either too deep or too little peat for sawgrass
Saw Grass	--	17 square miles; Hallapata Swamp
1st Rate Hammock	--	A few small hammocks within sawgrass
Savanna Wet Savanna	A few pines, 1 cabbage palm, 1 myrtle	Along eastern side of “Saw Grass”; intermediate between “Saw Grass” and “Pineland”?
Bay Swamp Bay Gall	Bay	Small; west side; with “Low Prairie” and “Swamp”

a. Surveyed by M.A. Williams in June 1853

Township 38, Range 39

With the exception of one or two townships on the southern border of the watershed, Township 38, Range 39 appears to be the least developed (**Figure E-5**) of the five, lending itself to comparisons between present day topographical maps and the 130-year old township plat map. Regional drainage almost certainly affects the township, but local ditch systems seem to be less developed here than elsewhere in the watershed (**Figure E-1**). The survey notes are repetitively consistent, all “3rd Rate Pine & Ponds” with pines as witness trees. Comparison of the township plat map (**Figure E-2**) with the USGS Andantino NW topo quad map (**Figure E-3**) suggests a close match in wetland delineation. The hammock found on the Section 15-22 border appears to still be present (benchmark elevation there of 31 feet above sea level). Elevations seem to indicate a very flat landscape, ranging from 29 to 31 feet, with the 30-foot contour line often being the coincident with the edge of the wetlands. The topo quad map also suggests that many of the wetlands are elongated and interconnected in the northwest-southeast direction. Green Ridge, reaching 35 feet, runs with the same northwest-southeast orientation through Sections 11, 13, and 24. A single note in the township survey, “18.00 [chains] to Pond Running Water E S E” (northern boundary, Section 11, Course W), suggests that drainage from this location east of Green Ridge might proceed toward the South Fork of the St. Lucie River. Elongated, interconnected wetlands oriented northwest-southeast could be consistent with this, but no other flow information is available from the 1853 notes. Landscape categories reported in the Government Land Office field notes for Township 38, Range 39 are presented in **Figure E-2**. Landscape categories reported in the Government Land Office field notes for Township 38, Range 39 are presented in **Table E-3**.

Table E-3. Landscape Categories Reported in the Government Land Office Field Notes for Township 38, Range 39[a]

Landscape Category	Witness Trees	Comments
All 3rd Rate Pine & Ponds	All pines	Matrix; includes “Ponds”
Ponds or Saw Grass Pond (1 only)	1 bay, probably on edge	Vegetation unclear, but probably to deep or too little peat for sawgrass
Hammock	--	One small hammock
Savanna	1 pine, might have been outside	A few small areas

a. Surveyed by M.A. Williams in May and June 1853

Township 40, Range 40

Township 40, Range 40, was chosen as approximately two-thirds of the township is untrained natural area, and, therefore, might provide a model for the predrainage condition of the more developed townships further north in the St. Lucie River watershed. The West of Rood (West Palm Beach 2 NE) orthophoto map suggests that there might be an important difference from townships further north in the watershed as the wetlands in this township generally appear more circular and less directional, and the regional pattern less oriented than was the case in Township 38, Range 39.

Although field notes were not locally available for this township (they should be obtainable from Tallahassee), comparison of the plat map with the USGS orthophoto map confirmed that the plat map underestimates the large quantity of wetlands (which appear to be ponds with areas of cypress), showing only those crossed by the section lines. Comparison of Section 35 suggests a good match for those shown. Elevations range from 20 to 25 feet above sea level, with lower elevations to the northeast.

Township 40, Range 38

Township 40, Range 38 was examined as a proxy for Township 40, Range 40, due to the local unavailability of field notes for the latter. Information from two different surveyors is available for this township: M.A. Williams surveyed the north boundary in August and September of 1853, and W.J. Reyes surveyed the whole township in February 1855. Elevations are 24 to 26 feet above sea level, with one isolated spot in the northeastern corner of 30 feet. As for other townships, the Port Mayaca and Barley Barber Swamp (Okeechobee 4 SE) topo quad maps, indicated many more wetlands than those shown on the township plat. The field notes indicate numerous wetlands, generally either "ponds" or "cypress swamps." This could be an underestimate, as this area appears to have been significantly affected by drainage. Landscape categories reported in the Government Land Office field notes for Township 40, Range 38 are presented in **Tables E-4** and **E-5**.

Table E-4. Landscape Categories Reported in the Government Land Office Field Notes for Township 40, Range 38 (northern boundary only)[a]

Landscape Category	Witness Trees	Comments
3rd Rate Pine 3rd Rate Pine & Ponds	Pines	Includes "Ponds"
2nd Rate Hammock	Cabbage palm	Cabbage hammock
2nd Rate Pine & Cabbage & Hammocks & Sawgrass Ponds	Pine, cabbage	Includes "Saw Grass Ponds" and "Hammocks"; "Cabbage" appears to be mixed with "Pine"
1st Rate Hammock	--	
Savanna	Cabbage palms, pines	

a. Surveyed by M.A. Williams in August and September 1853

Table E-5. Landscape Categories Reported in the Government Land Office Field Notes for Township 40, Range 38[a]

Landscape Category	Witness Trees	Comments
3rd Rate Cypress (Swamp) Pine & Palmetto		Includes "Cypress Swamp", "Pine [Land]", "Ponds" (many; several per mile) and "Saw Grass & Cypress (Pond)"
Cypress Swamp	Cypress, pine, cabbage, bay, myrtle	Many; probably as frequent as "Ponds"
Pine [Land]	Pine, cabbage	
3rd Rate (flat) Pine & Palmetto (land) 3rd Rate Sawgrass Pine & Palmetto	Pines, cabbage	Includes "Ponds" (many; several per mile), "Shallow Pond" (1) and "Saw Grass"
2nd Rate Pine & Cabbage	Pines	Includes: "Ponds" (many; several per mile) and "Willow Swamp" (1)
Prairie	Myrtle, maple, cabbage	Not much, but distinguished from "Saw Grass"
Hammock		Not many

a. Surveyed by W.J. Reyes in February 1855

Cross-Township Landscape Features

Figure E-7 shows a portion of the Halpatta Swamp (Allapattah Flats) that extended northwest to southeast across five townships. This area of “impracticably” dense and boggy sawgrass may have included peat soils and may have drained overland along a northwest-southeast axis. Much of original extent has disappeared under drainage and cultivation.

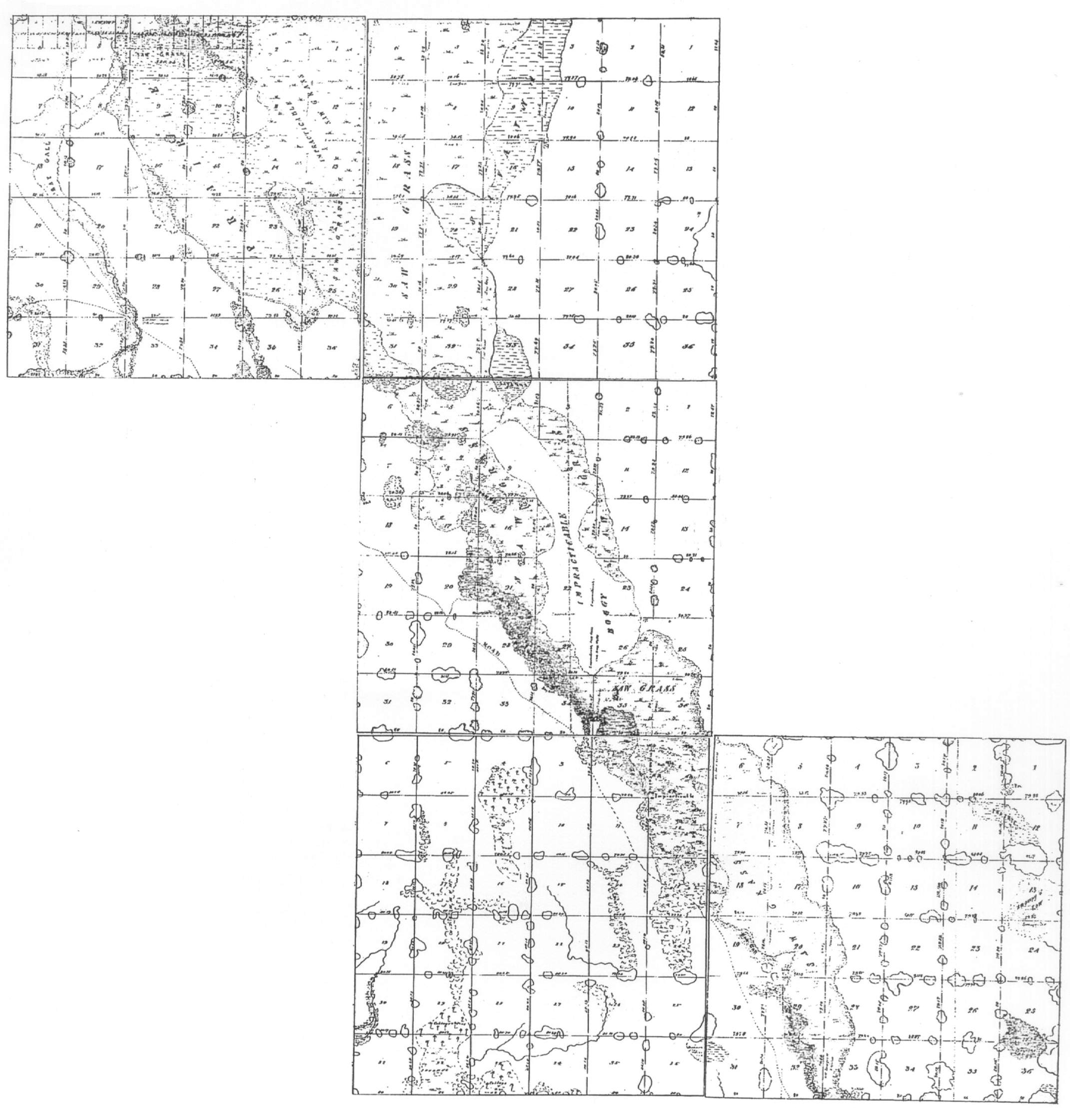


Figure E-7. Mosaic of Five Township Plats from Townships 37 to 39 South, and Ranges 37 to 39 East, Showing Extensive Sawgrass Marsh, Too Dense and Wet, Hence “Impractible” to Survey.

Headwaters of the St. Lucie River

Figure E-8 is a township plat map that includes the South Fork of the headwaters of the St. Lucie River. It appears similar to the township plats mapping the North Fork (not shown; Townships 35 and 36, Ranges 39 and 40). It is tempting to assume that all of the "Prairie" and "Ponds" physiographic regions present within the northern part of the watershed contributed surface runoff to the North Fork of the St. Lucie River, and that the flow through the North Fork was much greater than through the South Fork. While the North Fork likely passed more water than the South Fork, it is important to note that no actual evidence was found within the township survey plats or field notes documenting surface runoff. The difference between the two forks may be less than expected. It is possible that the Halpatta Swamp/Allapattah Flats area may have been connected to the South Fork, but this certainly bears additional investigation.

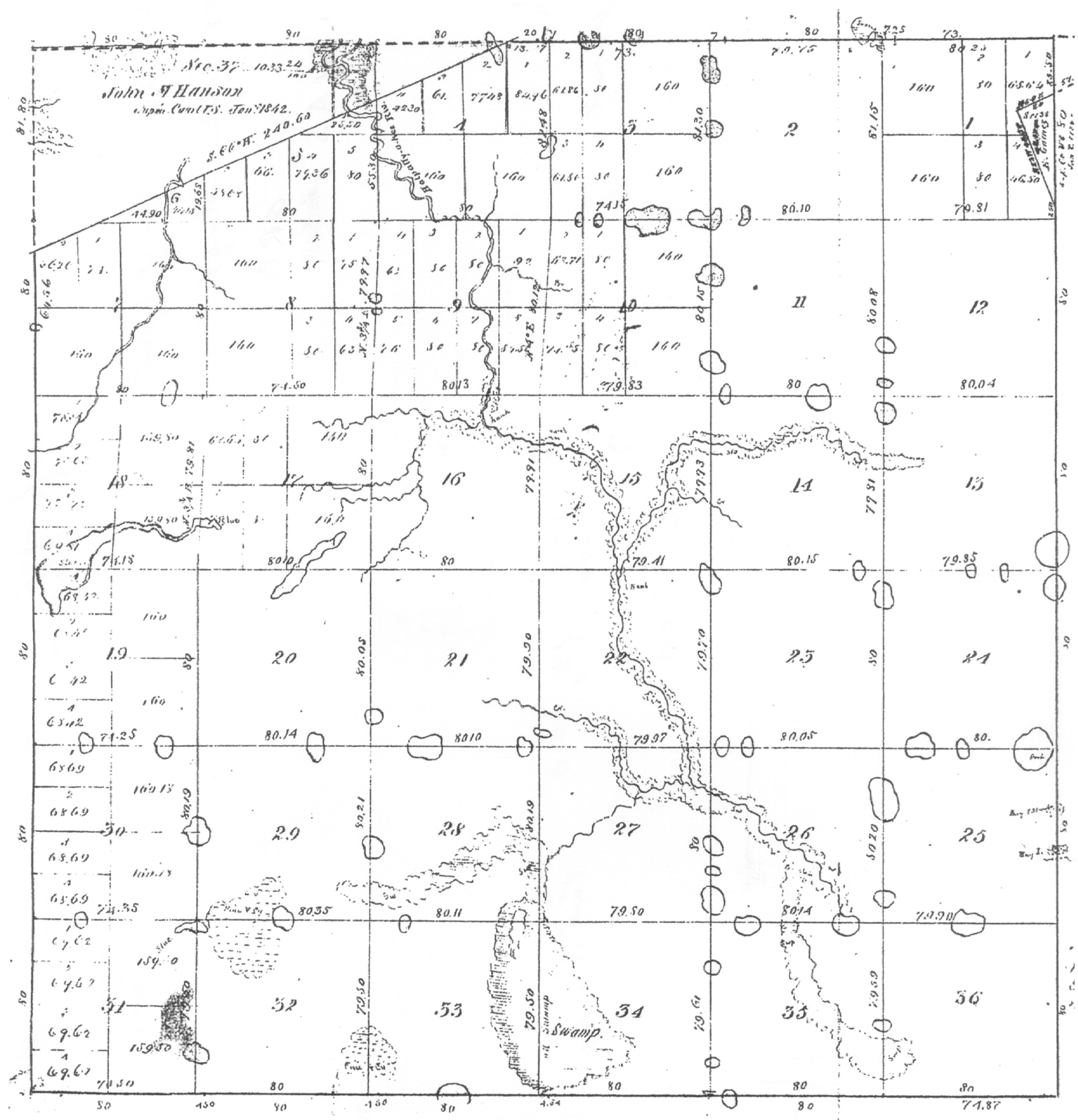


Figure E-8. Township 39 South, Range 41 East, Showing Several Branches of the South Fork of the St. Lucie River (surveyed by M.A. Williams in June 1853)

CONCLUSIONS

The conclusions presented here are based on examination of field notes and plat maps, as described above, for five of approximately 30 townships making up the watershed. Plat maps for a number of additional townships were examined briefly. The author has not had the opportunity to explore the watershed in person.

Three main physiographic regions appear to have been present in the predrainage watershed: an area of “Pine & Ponds” mosaic, an area of “Prairie & Ponds” mosaic, and an area referred to as the Halpatta Swamp, later as the “Allapattah Flats.” Ponds, whether of sawgrass, open water or “grassy species,” appear to have been very common throughout the pine and the prairie areas. The difference in the nonpond “matrix” found in the “Prairie” compared to that found in the “Pine” areas is not completely clear, but the “Prairie” matrix appears to have been covered by standing water for longer periods each year, resulting in a reduced density or complete absence of pine trees.

All three physiographic regions appear to have been very flat, with the elevation difference between pineland and pond probably often as little as two feet. It is likely that the depths of the depressions varied, with the shallower depressions forming either open water or wet prairie-type ponds, and the deeper depressions accumulating peat deposits and supporting sawgrass vegetation. Once the deeper depressions had accumulated peat, the elevation difference between peat surface and surrounding pineland surface may have been similar to the elevation difference between pineland and the bottom elevation of the open water, sand-based ponds.

The “Prairie” mosaic was described primarily in the northern portion of the St. Lucie River watershed. The sawgrass marshes and bordering forested wetlands (“Bay Galls” and “Cypress Swamps”) that formed the Halpatta Swamp were present along the western edge of the watershed, along the eastern foot of the high northwest-southeast ridge. Cypress occurring in pond-like patches seems to have been confined to the southernmost townships of the watershed.

Although there appears to have been variation in spatial pattern and apparent interconnection between the ponds present in the watershed, generally there does not appear a strong suggestion of extensive connection nor of extensive surface runoff. The most important contribution of the watershed to the St. Lucie River may have been more through ground water contribution to base flow than through surface runoff. The long duration of standing water in ponds and even longer duration in the sawgrass marshes may be of assistance in estimating duration of the base flow recession during each year’s dry season.

The presence of extensive surface water throughout the watershed, the probable limited degree of surface runoff, and the examination of townships surrounding the headwaters of the North and South Forks of the St. Lucie River tentatively suggest that the difference in discharge between the two forks may be smaller than might at first appear.

RECOMMENDATIONS

It is suggested that this research be made available for critique and for use by a wider audience through publication in an appropriate technical journal. As this research effort was of very limited duration, it is suggested that prior to publication it be augmented by 1) further examination of Government Land Office surveys of the remaining townships within the watershed; 2) identification and examination of additional predrainage narrative sources regarding the watershed; 3) examination of current county soil surveys covering the watershed; 4) ground inspection of selected areas including measurements of local topography and water depths; and 5) further investigation of watershed-scale patterns using estimated or measured topographical information at 1-foot resolution.

Prior to publication in a technical journal, the figures accompanying this report should be enhanced for clarity. Features to be added or improved include improved line quality, addition of watershed boundaries, and correction of spatial extent.

REFERENCES

Davis, J.H., Jr. 1943. *The Natural Features of Southern Florida*. Geological Bulletin 25, Florida Geological Survey, Tallahassee, FL.

Florida Surveyor General's Office. 1853. A plat exhibiting the state of the surveys in the State of Florida with references. 18 miles to 1 inch (1:1,140,000), St. Augustine, FL.

Hopkins, C.F. 1853. Field notes and plat map for United States Survey of Township 36 South, Range 37 East. Surveyed July, 1853. Surveyor General's Office, Florida, St. Augustine, FL.

Jones, L.A., R.V. Allison, G.D. Ruehle, et al. 1948. *Soils, Geology, and Water Control in the Everglades Region*. Bulletin 442, University of Florida Agricultural Experiment Station, Gainesville.

Konya, K. 2000. Personal communication on November 21, 2000. South Florida Water Management District, West Palm Beach, FL.

MacKay, G. 1846. Letter from G. MacKay to the Surveyor General of Florida. In: Knetsch, J., (ed) 1993, *Letters and Reports to Surveyor General, 1825-1847*, Bureau of Survey and Mapping, Florida Department of Environmental Protection, Tallahassee, FL, pp. 475.

Matson, G.C., and S. Sanford. 1913. *Geology and Ground Waters of Florida*. Water Supply Paper 319, United States Geological Survey, Washington, D.C.

Niblack, S.L. 1882. Report on the boundary of the Okeechobee Drainage District. Lake City, Florida, June 27, 1882. In: *Minutes of the Trustees, December 18, 1882 Meeting*, Volume III. 1904, Trustees of the Internal Improvement Fund, Tallahassee, FL, pp 191-195.

Randolph, I., Cunningham, and Hallowes. 1919. *Report of surveys and studies of the North St. Lucie River Drainage District*. Isham Randolph and Company, and Cunningham and Hallowes, Jacksonville, FL.

Reyes, W.J. 1855a. Field notes and plat map for United States Survey of Township 40 South, Range 38 East. Surveyed January and February 1855. Surveyor General's Office, Florida, St. Augustine, FL.

Reyes, W.J. 1855b. Plat map for United States Survey of Township 40 South, Range 38 East. Surveyed January 1855. Surveyor General's Office, Florida, St. Augustine, FL.

Stephens, J.C., and L. Johnson. 1951. Subsidence of organic soils in the Upper Everglades region of Florida. *Soil Science Society of Florida Proceedings* 11:191-237.

Williams, M.A. 1853. Field notes and plat map for United States Survey of Township 37 South, Range 38 East. Surveyed June, 1853. Surveyor General's Office, Florida, St. Augustine, FL.

Williams, M.A. 1853. Field notes and plat map for United States Survey of Township 38 South, Range 39 East. Surveyed May and June 1853. Surveyor General's Office, Florida, St. Augustine, FL.

APPENDIX F
ESTIMATING THE EXTENT OF THE OLIGOHALINE ZONE IN THE NORTH FORK OF THE ST. LUCIE RIVER AND ESTUARY UNDER LOW FLOW CONDITIONS

Chenxia Qiu, SFWMD

SUMMARY

The location of the 5-parts per thousand (ppt) isohaline zone in the North Fork of the St. Lucie River and Estuary under steady state conditions is estimated using two methods: a one-dimensional analytical solution and a two-dimensional hydrodynamic Research Management Associates, Inc. (RMA) model. The 5-ppt isohaline zone is traditionally considered to be the transition between the saltier mesohaline and the fresher oligohaline habitats. Its location is used here to define the downstream extent of viable oligohaline habitat under low flow situations. The one-dimensional analytic method is calibrated using salinity data collected at the Kellstadt Bridge (FOS station 1), and flow data collected at the Gordy Road Structure during 1999 and 2000. The two-dimensional RMA model was calibrated at the Roosevelt Bridge, which crosses the St. Lucie Estuary. This calibration is discussed in **Appendix H**. A logarithmic relationship is developed relating the salt intrusion position to the discharge rate. The relationship is similar for both solution methods. This relationship can be used to estimate the extent of the viable oligohaline zone in the riverine portions of the North Fork. Based on recommendations from the expert review of models used to support the development of the St. Lucie River and Estuary minimum flows, additional calibration for the hydrodynamic and salinity models was performed. Results are presented in the addendum to this appendices.

BACKGROUND

This work is conducted as part of the Indian River Lagoon Restoration Feasibility Study (USACE and SFWMD, 2001) and also as part of the effort to establish minimum flow and levels (MFLs) for the St. Lucie Estuary. Protection of a viable oligohaline habitat depends in part on the maintenance of sufficient flows within the riverine reaches of the St. Lucie River watershed. Since most of the riverine portions of the watershed are in the historic North Fork, this paper is limited to North Fork modeling. Previous hydrodynamic modeling (**Appendix H**) within the St. Lucie Estuary focused on periods of moderate to high runoff when the riverine portions of the estuary were fresh. For this reason, previous modeling did not extend into the riverine portions of the estuary.

Minimum flow conditions are associated with droughts and periods of low rainfall. Under low flow conditions, salinity throughout the estuary increases and the oligohaline area is reduced as higher salinity destroys or displaces oligohaline flora and fauna. This MFL work is directed at estimating the extent of the oligohaline under various low flow conditions. Since flows are relatively stable during low flow periods it is assumed that steady state solutions can adequately predict salinity within the upstream reaches.

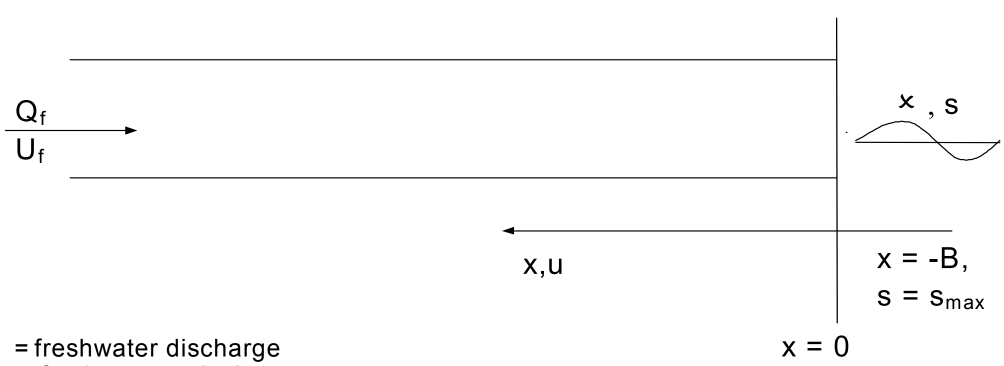
This appendix describes two steady state methods for predicting the location of the 5-ppt isohaline zone. The calibration of the analytical method is also described. The methods are applied to two minimum flow scenarios (the end of a 1-in-10 year drought). One MFL situation is North Fork flows under predeveloped (Natural System Model [NSM]) conditions. The other scenarios is flow from today's watershed (1995 Base Case) under the same low rainfall conditions. The equivalent flow-location relationships exist for both the 1995 Base Case and NSM conditions using either the analytical or RMS method. The resulting simple flow-location relationship is being applied elsewhere in the continued development of MFL criteria.

ONE-DIMENSIONAL ANALYTICAL SOLUTION

Basic Equations

The objective of the one-dimensional analytical solution is to calculate the location of the isohaline zone in a tidal driven channel with freshwater discharge. The isohaline zone will have 5-ppt or 10-ppt salinity. The method described below in **Figure F-1** and the equations came from Ippen (1966).

At x = 0, ocean end; at t = 0, it is low tide



Q_f = freshwater discharge
U_f = freshwater velocity
s_{max} = the maximum salinity at the tidal boundary
B = the distance from tidal boundary to ocean where salinity reaches s_{max} at low tide

Figure F-1. Sketch of Salinity Intrusion in a Tidal Influenced Channel at Low Tide

Equations 1 and 2 are the basic equations of the one-dimensional analytical solution:

$$\frac{\partial s}{\partial t} + u\frac{\partial s}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial s}{\partial x}\right) \tag{1}$$

At any point, the flow velocity in the channel is equal to the sum of the velocity due to tidal motion u(x,t) and the freshwater velocity $-U_f$, thus

$$\frac{\partial s}{\partial t} + u(x,t)\frac{\partial s}{\partial x} - U_f \frac{\partial s}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial s}{\partial x}\right) \tag{2}$$

Where $D_x(x,t)$ is the diffusion coefficient.

Solution

Salinity Distribution at Low Tide

The salinity distribution at low tide is determined using Equation 3.

$$\ln \bar{s} + C_2 = -U_f \int \frac{dx}{D_x} \tag{3}$$

Diffusion without Density Difference

The diffusion coefficient can be stated as follows:

$$D_x = 14.2hu\frac{\sqrt{2g}}{C_c} = 7.1hu\sqrt{f}, \quad C_c = \sqrt{8g/f} \tag{4}$$

The average value of D_x in a tidal cycle linearly depends on u, which is computed from tidal propagation and decreases with x in an upstream direction. For uniform cross-sections, a simplest functional relationship can be used:

$$D_x = \frac{D_0 B}{x + B} \tag{5}$$

Therefore,

$$\ln \frac{c}{c_0} = -\frac{U_f}{2BD_0}(x + B)^2 \tag{6}$$

at x=-B, c= c_0.

Diffusion with Density Difference

The diffusion with density difference is calculated using Equation 7:

$$\ln \frac{s}{s_{\max}} = -\frac{U_f}{2BD_0'}(x_l + B)^2 \qquad \text{for } (x_l + B) > 0 \tag{7}$$

The minimum salinity intrusion length at low tide:

$$L_m = x_l = B\left(\sqrt{-\frac{2D_0'}{U_f B}\ln\frac{s}{s_{\max}}} - 1\right) \tag{8}$$

The maximum salinity intrusion length at high tide is in the range of L_m and L_m+B.

Determine B and D_0'

The distance from the tidal boundary to the ocean where salinity reaches s_{max} at low tide (B) is determined using Equation 9:

$$B = \frac{u_{\max}}{\sigma}(1 - \cos\sigma t_B) \tag{9}$$

The diffusion coefficient (D_0') is calculated using Equation 10. Because the salinity is in the range of 5 to 15 ppt, assume D_0' = D_0

$$D_0' \sim hu_{\max}\frac{\sqrt{2g}}{C_c}, \quad C_c = \frac{1}{n}R^{1/6}, \quad R = \frac{bh}{b + 2h} \tag{10}$$

Where t_B is the time the salinity at the entrance reaches the maximum value s_{max} and s_{max} is the maximum salinity at low tide at x_l = 0. The final D_0' is obtained from calibration. t_B and s_{max} can be identified from the salinity profile at the ocean end.

Input Parameters

The input parameters for the one-dimensional analytical solution are provided in **Table F-1**.

Table F-1. Input Parameters

Symbol	Parameters	Sources
b	Width	Cross-section profile
h	Depth	Cross-section profile
n	Manning coefficient	
u_{max}	Maximum velocity at the tidal end boundary	Tidal boundary
s	Tidal frequency	Tidal boundary
U_f	Freshwater velocity	Fresh water discharge Q_f and river cross-section area A
s_{max}	Maximum salinity at tidal end boundary	Salinity series at tidal boundary
t_B	Time the salinity at the entrance reaches the maximum value s_{max}	Salinity series at tidal boundary

Implementation Procedures

- Determine σ, $u_{max,}$ and s_{max} from the tidal boundary condition
- Determine river depth h and calculate U_f = Q/A, where Q is the freshwater discharge rate at cubic meters per second and A is the cross-section area of the river
- Determine t_B and s_{max} with the salinity series boundary condition
- Calculate B and D_0' from Equations 9 and 10
- Calculate minimum salinity intrusion at low tide with equation (8)

Calibration

The calibration data set is composed of three parts: Florida Oceanographic Society (FOS) Station 1 salinity data (**Figure F-2**), Gordy Road Structure flow data, and Kellstadt Bridge salinity and current data maintained by the United States Geological Survey (USGS) (**Figure F-3**).

Salinity data from FOS Station 1 was taken by volunteers every week since 1998. Station 1 is located 1 mile north of the Prima Vista Bridge (section N044) and 4 to 5 miles north of the Kellstadt Bridge (section N067) (Longitude 80° 19.887' W, Latitude 27° 19.724' N).

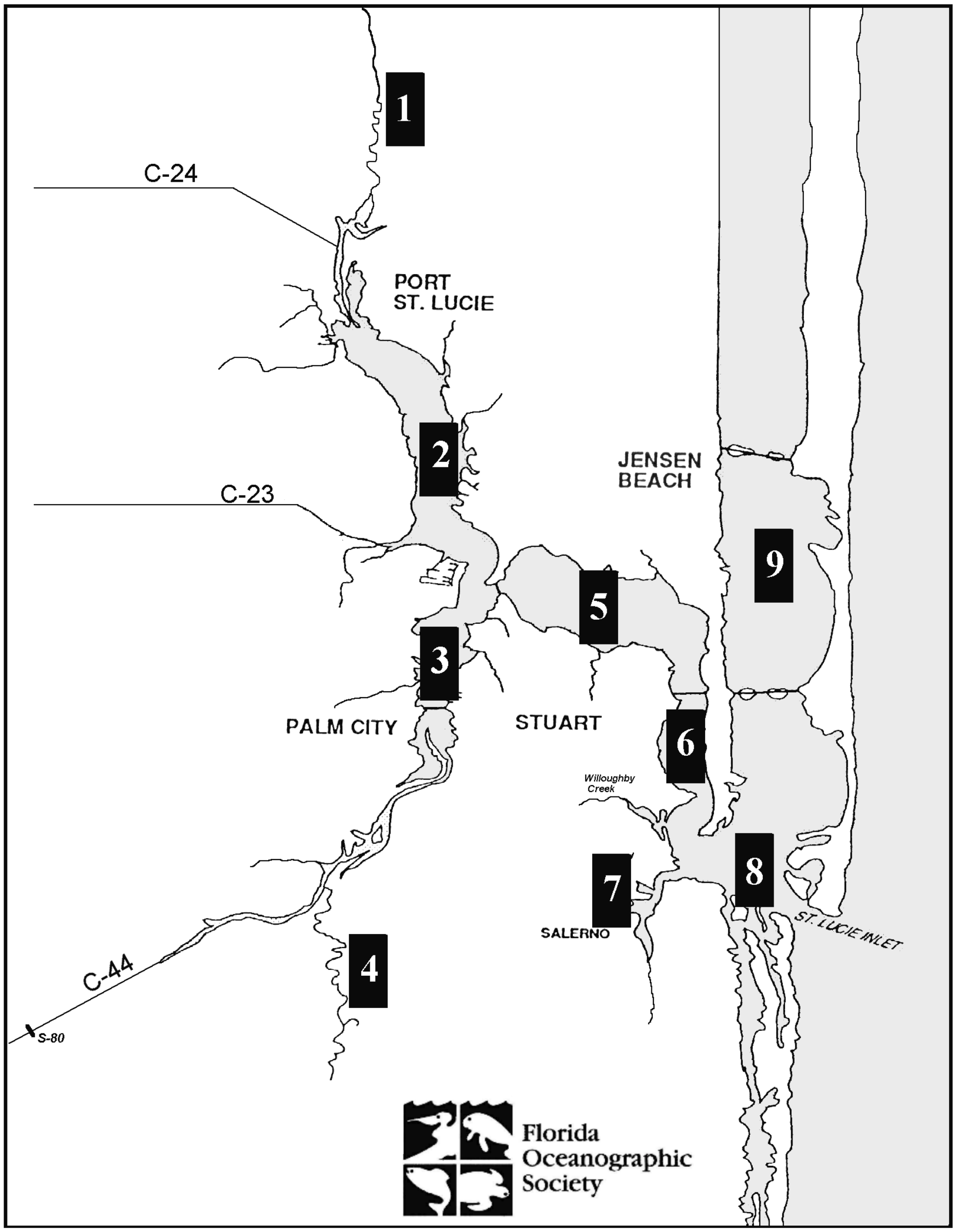


Figure F-2. Florida Oceanographic Society Monitoring Stations

The Kellstadt Bridge station was monitored by USGS until 2000. The monitoring data collected includes water surface elevation, current, and salinity at the top and bottom layers.

The discharge rate at the Gordy Road Structure on Ten Mile Creek has been monitored since 1999. The discharge rate on the North Fork is estimated based on drainage area (**Table F-2**). The approximation in North Fork discharge estimation is probably one of the greatest error terms in this simulation.

Table F-2. North Fork Discharge Derived from Gordy Road Structure Discharge

Drainage Basins	Drainage Area (Acres)
Ten Mile Creek	29,380
Five Mile Creek	7,000
North Fork - Total	105,613
North Fork - uncontrolled area flowing into North Fork	63333
$Q_{NF} = Q_{TMC} * (1 + 63,333/29,380) = Q_{TMC} * 3.16$ Q_{NF} is the total discharge on the North Fork and Q_{TMC} is the discharge on Ten Mile Creek measured at the Gordy Road Structure	

Based on 22 cross-section profiles, it was determined that the North Fork is deeper and wider (230 feet) and meanders down from the Prima Vista Bridge (N035-N072). From Prima Vista Bridge to the upper reach (N01-N035), the river is narrower (85 feet) and shallower. During calibration, the width is fixed constant to 6.5 feet between FOS Station 1 and Kellstadt Bridge. Three calibration scenarios were selected based on the comparison of overlap periods among these 3 data sets (**Table F-3**).

Table F-3. Calibration Scenarios

Calibration scenarios	**March 19, 2000**	**January 23, 2000**	**December 19, 1999**
Freshwater discharge (Q_f) (cubic feet per second)	90	180	260.9
Kellstadt Bridge salinity (ppt)	12	8	3
Salinity at FOS station 1 (north of Prima Vista Bridge) (ppt)	4	2	1.2
Maximum Tidal velocity (u_{max}) (meters per second)	0.3	0.3	0.2
Maximum salinity at tidal end (ppt)	14.8	10.2	5
Minimum salinity at tidal end (ppt)	11	5	1.5
Width (d) (feet)	230		
Depth (h) (feet)	6.5		
Length (mile)	6.4		
Manning coefficient	0.04		
t_B	0.45 Tidal Period		

The diffusion coefficient is crucial for salinity intrusion due to tidal mixing and density gradient. The density gradient effect is reflected in freshwater discharges and salinity at the tidal end. To account for this, the diffusion coefficient is adjusted with a correction factor in the prediction:

$$D_0' = D_0 \cdot f(Q_f) \cdot f(\frac{s_{max}}{s_{min}}) = D_0 \cdot \frac{Q_f\,(calibration\ base)}{Q_f} \cdot \frac{\ln(\frac{s_{max}}{s_{min}})(calibration\ base)}{\ln(\frac{s_{max}}{s_{min}})} \qquad (11)$$

Analytical solution is limited with uniform sections. Therefore, average depth is adjusted to 5 feet at low flow conditions based on the two-dimensional simulation results, which is described in the next section.

With the progress of the tide into the river, the velocity amplitude is damped exponentially. In addition, the celerity of wave is reduced by a factor related to wave length. This factor is 0.71 to 0.94 (Ippen, 1966). A conservative correction factor of 0.9 is used.

The one-dimensional analytical solution is limited with simplifications. Through the calibration and prediction process, river depth, river width, maximum salinity, and velocity at the tidal boundary are identified as sensitivity parameters. River depth and width are simplified as uniform. The measured velocity at the Kellstadt Bridge by the USGS is used in the prediction. In addition, the diffusion coefficient is assumed linearly decreased with the propagation of tide. All these approximations introduce uncertainty into the prediction and reflect the limitation of the method.

TWO-DIMENSIONAL SIMULATION ON EXTENDED ESTUARY GRIDS WITH THE RMA MODEL

The RMA finite element grid was extended from Kellstadt Bridge to the Gordy Road Structure. The new grid is shown in **Figure F-3**. The two-dimensional RMA model is calibrated around the Roosevelt Bridge in the St. Lucie Estuary by Hu (**Appendix H**). Due to time limitations, it was not further calibrated for the North Fork.

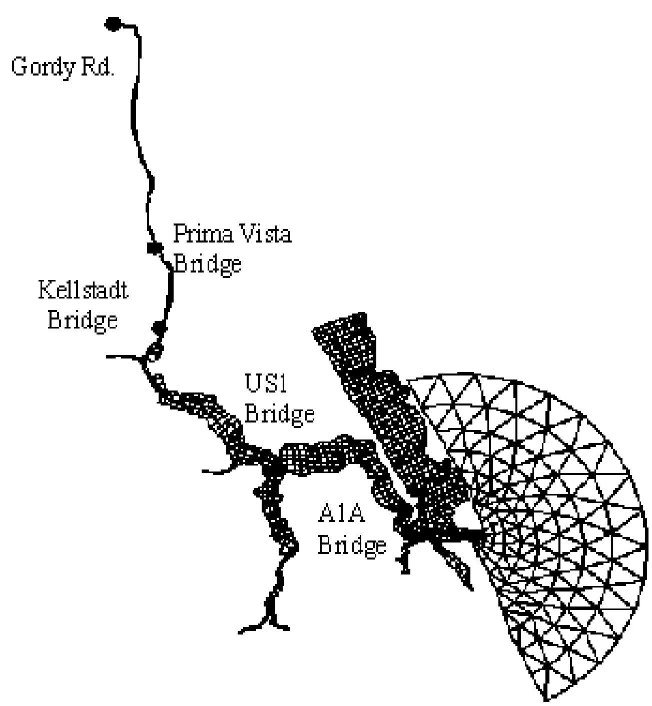


Figure F-3. Two-Dimensional Simulation Grid for the North Fork and the St. Lucie Estuary

RESULTS

Prediction scenarios were selected for 1995 Base Case and NSM model simulations based on the time periods when discharge is relatively stable. Five scenarios were selected for the 1995 Base Case simulations (**Figure F-4** and **Table F-4**) and four were selected for the NSM simulations (**Figure F-5** and **Table F-5**).

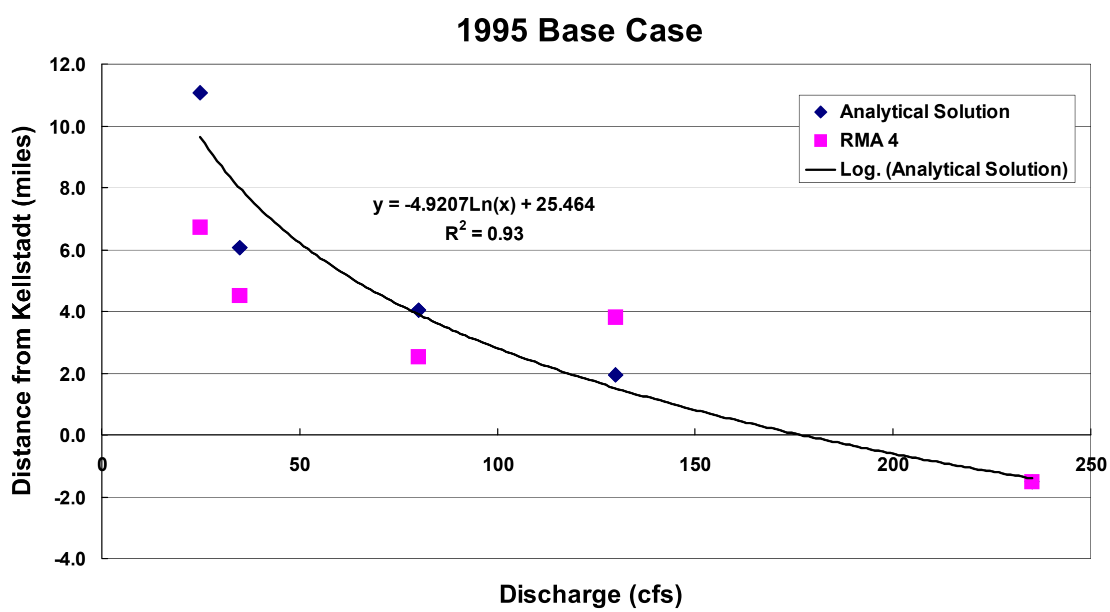


Figure F-4. Location of the 5-ppt Isohaline Zone for the 1995 Base Case Simulations

Table F-4. Prediction Scenarios for the 1995 Base Case

Julian Day	27-42	95-105	19-24	74-79	112-117
Q_f (cfs)	235	130	80	35	25
s_{max}		9.5	13	15	18
s_{min}		6	9	10.5	13
s_{avg}	3.8	8.5	11	12.5	15
L_{avg} (mile) from Kellstadt Bridge	0	2	3	6	11
% of NF length	0	0.14	0.22	0.3	0.5
L_{avg} compared to RMA 4 result	0	5.3	4.0	6.0	8.2
% of NF length	0	0.21	0.16	0.24	0.33

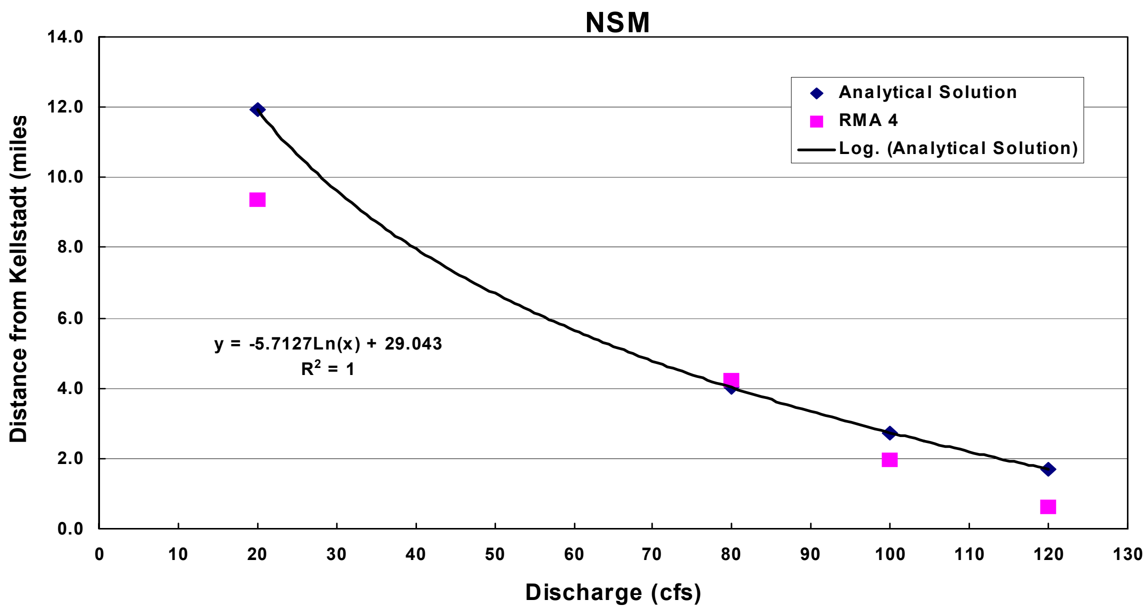


Figure F-5. Location of the 5-ppt Isohaline Zone for the NSM Simulations

Table F-5. Prediction Scenarios for the NSM Simulations

Julian Day	112-119	10-30	52-60	34-50
Q_f (cfs)	20	80	100	120
s_{max}	17.5	14	14	10
s_{min}	14	9	8	6.5
s_{avg}	16	11	10	8
L_{avg} (mile) from the Kellstadt Bridge	12	4	2.7	1.7
% of NF length	0.54	0.22	0.17	0.13
L_{avg} compared to RMA 4 result	10.9	5.7	3.4	2.1
% of NF length	0.43	0.23	0.14	0.08

Based on the results from the two methods, the location of 5-ppt isohaline zone and discharge rate has these relationships:

$L = -4.9 \ln(Q_f)+27$ for the 1995 Base Case

$L = -5.7 \ln(Q_f)+30.5$ for the NSM

When discharge is larger than 175 cfs for the 1995 Base Case, the 5-ppt isohaline zone is downstream of the Kellstadt Bridge on the North Fork.

CONCLUSION

Predictions of the location of the isohaline zone on the North Fork is conducted with simplifications for a quick solution. Compared with Kellstadt Bridge salinity data from USGS, it is concluded that RMA results underestimated the salt intrusion length on the North Fork, while the one-dimensional analytical solution result is limited by too many simplifications. Due to the limitation of time, the accuracy of the result is compromised.

This simulation will be applied to the determination of the oligohaline zone on the North Fork under minimum flow condition for three scenarios: 1995 Base Case, NSM, and 2050.

REFERENCES

Florida Oceanographic Society. 2000. *St. Lucie River Estuary Water Quality Outlook*. http://www.fosusa.org/St. Lucie Estuary.htm.

Ippen, A.T. 1966. *Estuary and Coastline Hydrodynamics*. McGraw-Hill Book Company, Inc.

Kjerfve, B. 1978. *Estuarine Transport Processes*. University of South Carolina Press, Columbia, SC.

McDowell, D.M., and B.A. O'Connor. 1977. *Hydraulic Behavior of Estuaries*. John Wiley & Sons, New York, NY.

USACE and SFWMD. 2001. *Central and Southern Florida Project, Indian River Lagoon South Feasibility Study, Draft Integrated Feasibility Report and Supplemental Environmental Impact Statement*. Jacksonville District, United States Army Corps of Engineers Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

ADDENDUM TO APPENDIX F

Hydrodynamic and Salinity Model Recalibration for the North Fork of the St. Lucie River

Calibration Data Set

Further calibration of the hydrodynamic and salinity model was conducted with a calibration data set. This data was collected during a 2.5-month period from September 1999 to December 1999. Water level was measured every 15 minutes at the St. Lucie Inlet by the Florida Department Environmental Protection (FDEP). Salinity and water level were measured at the A1A, Roosevelt, and Kellstadt Bridges. Velocity also was measured at the Kellstadt Bridge. Daily flow data was collected at the Gordy Road Structure on Ten Mile Creek. Discharge rates were determined for the C-23, C-24, and C-44 Canals, and the South Fork.

The discharge rate on the North Fork was estimated based on the Gordy Road Structure discharge rate and drainage area. This approximation still contributes the greatest error term in this simulation.

Inlet water level data provides a control at the tidal boundary. It is compared to the 1998 calibration work. This calibration work used the National Ocean and Atmospheric Administration (NOAA) tide book data as its boundary condition.

Simulation Grids and Calibration Stations

The original finite element grids were modified to reflect the meandering of the North Fork. The locations of the FDEP monitoring station at the inlet and the United States Geological Survey (USGS) stations at the A1A, Roosevelt, and Kellstadt Bridges are shown in **Figure F-6**.

Calibration Results

The simulation results of water surface elevation are compared with monitoring data from four stations (**Figures F-7** through **F-10**). The salinity calibration results at the A1A, Roosevelt, and Kellstadt Bridges are presented in **Figures F-11** through **F-13**.

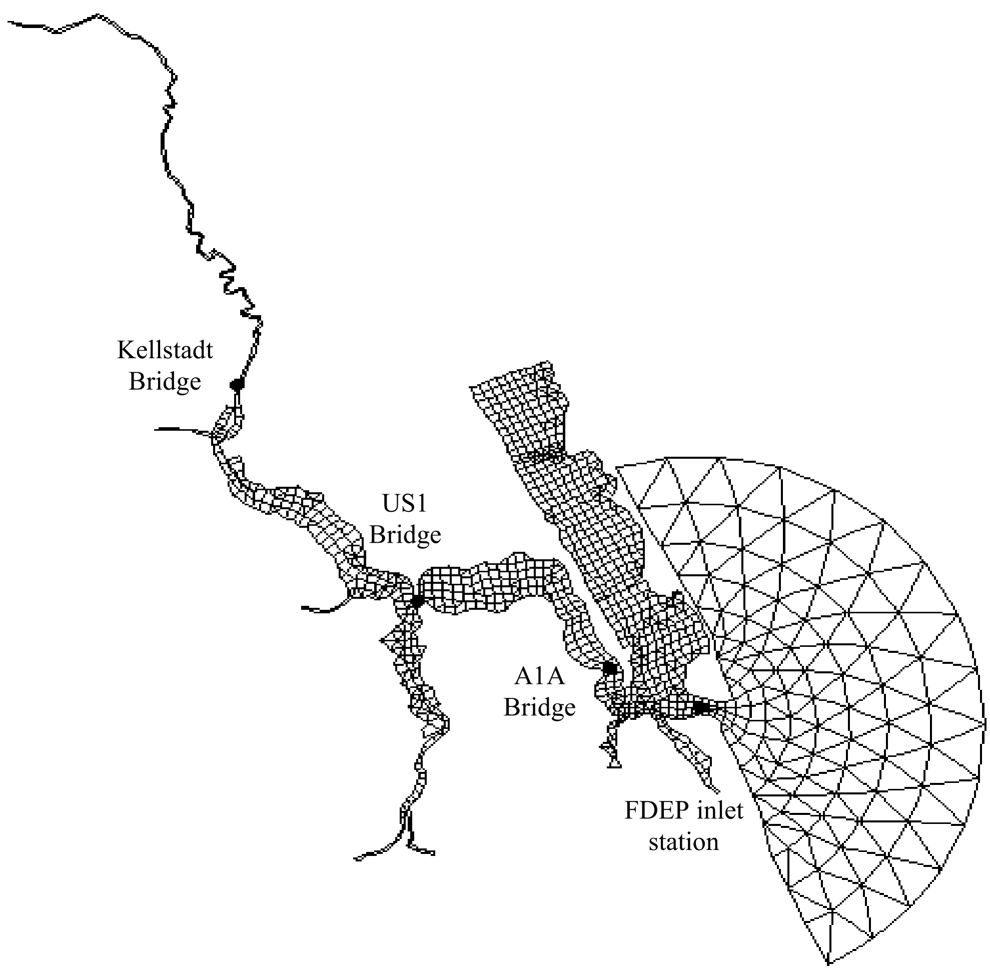


Figure F-6. Simulation Grids and the Locations of Monitoring Stations

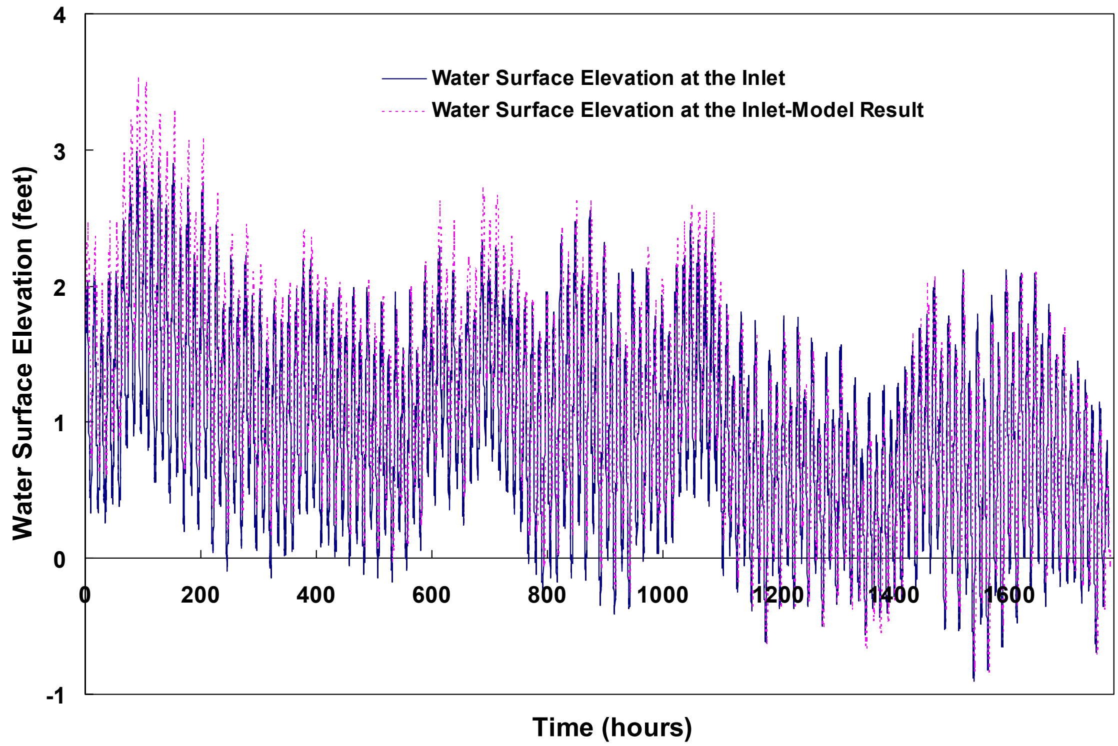


Figure F-7. Water Surface Elevation at the Inlet

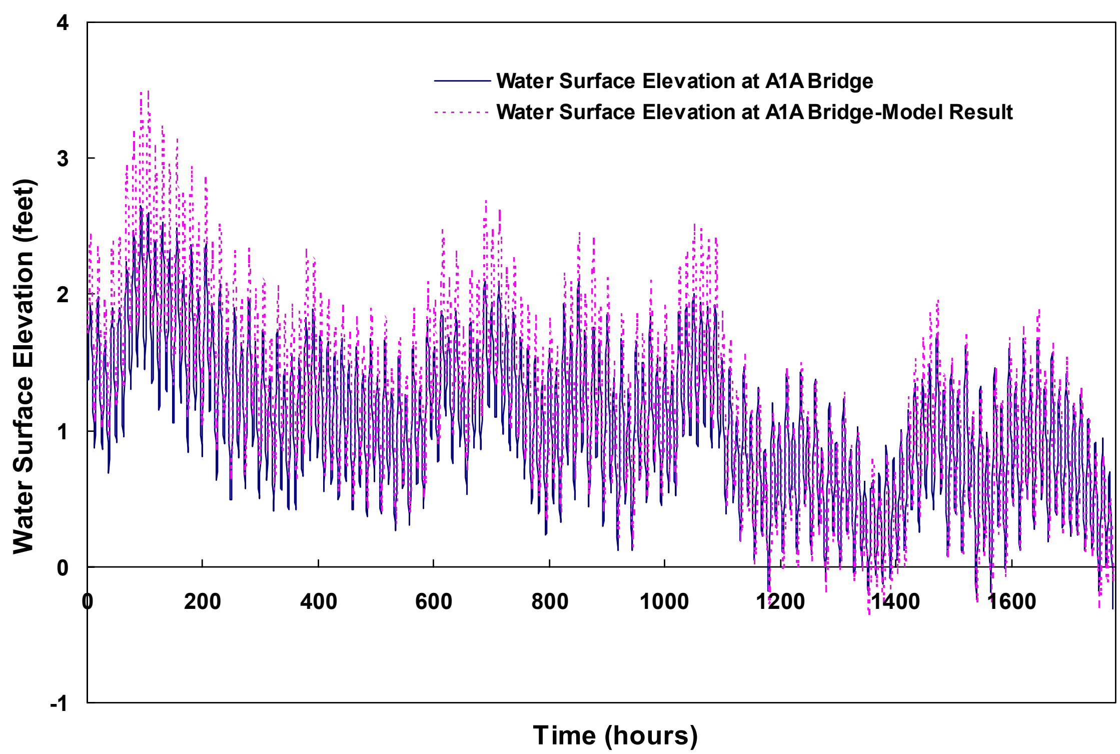


Figure F-8. Water Surface Elevation at the A1A Bridge

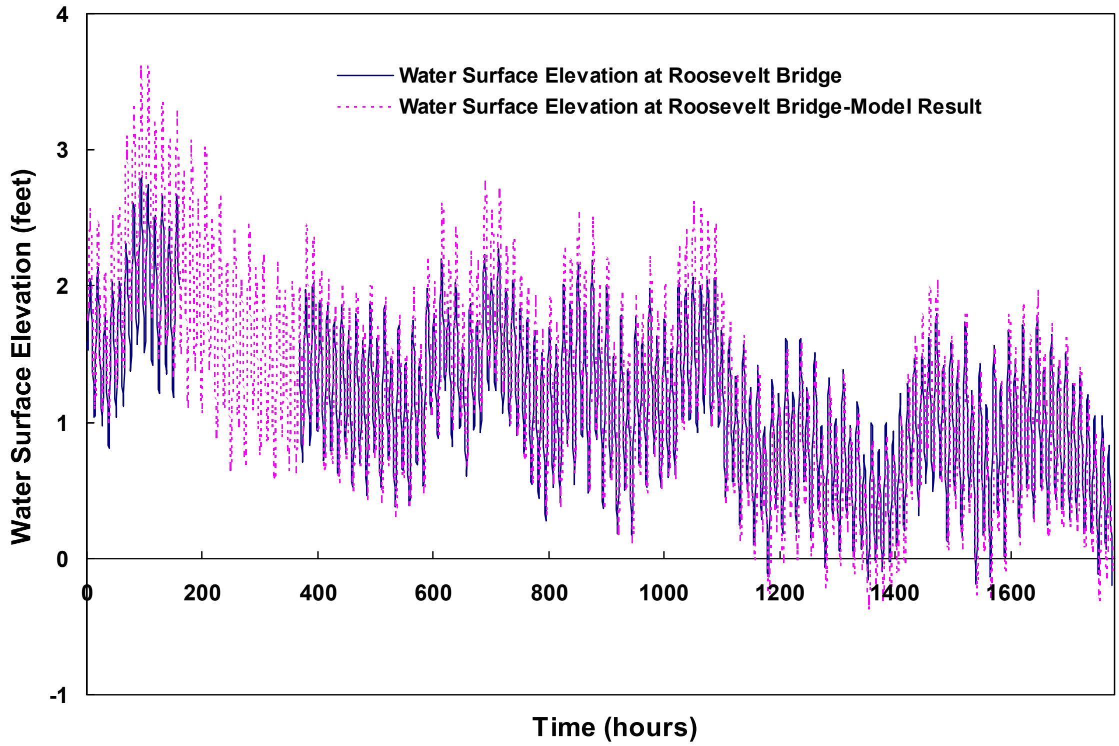


Figure F-9. Water Surface Elevation at the Roosevelt Bridge

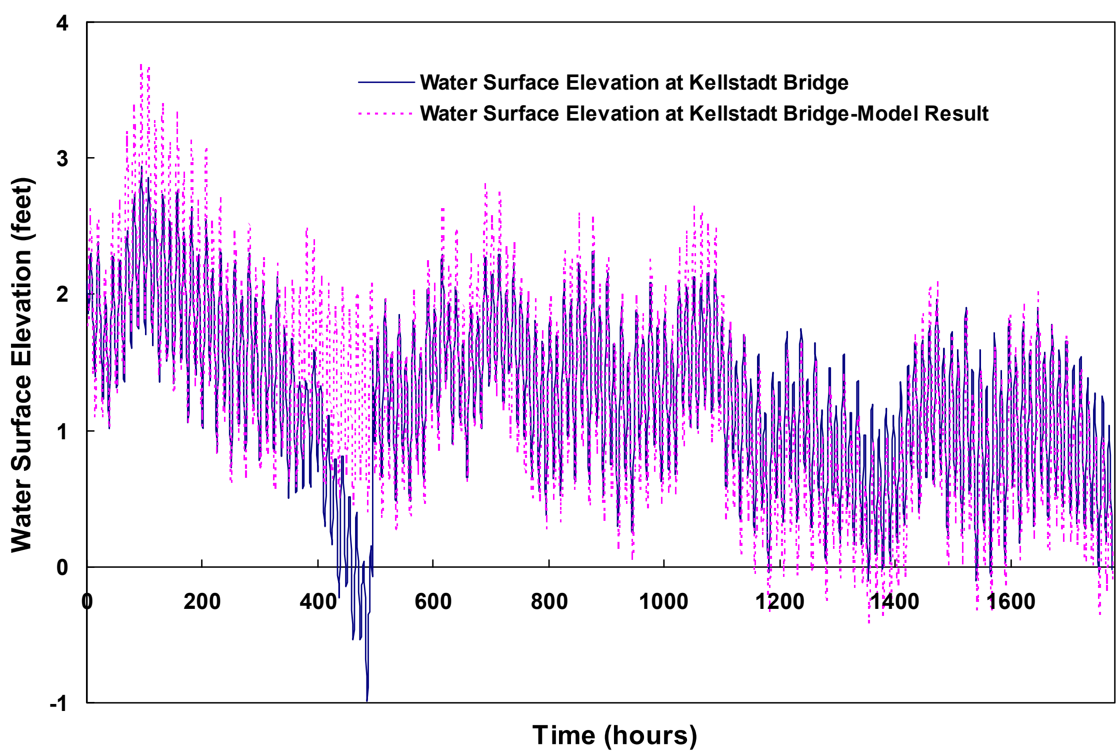


Figure F-10. Water Surface Elevation at the Kellstadt Bridge

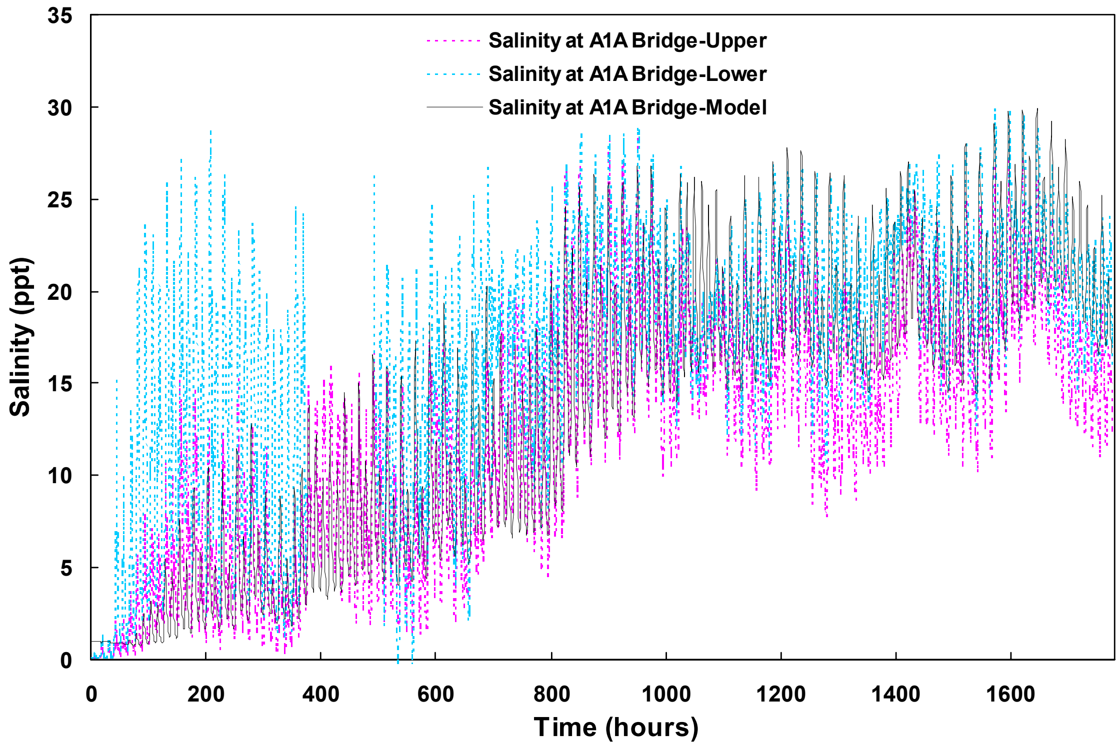


Figure F-11. Salinity at the A1A Bridge

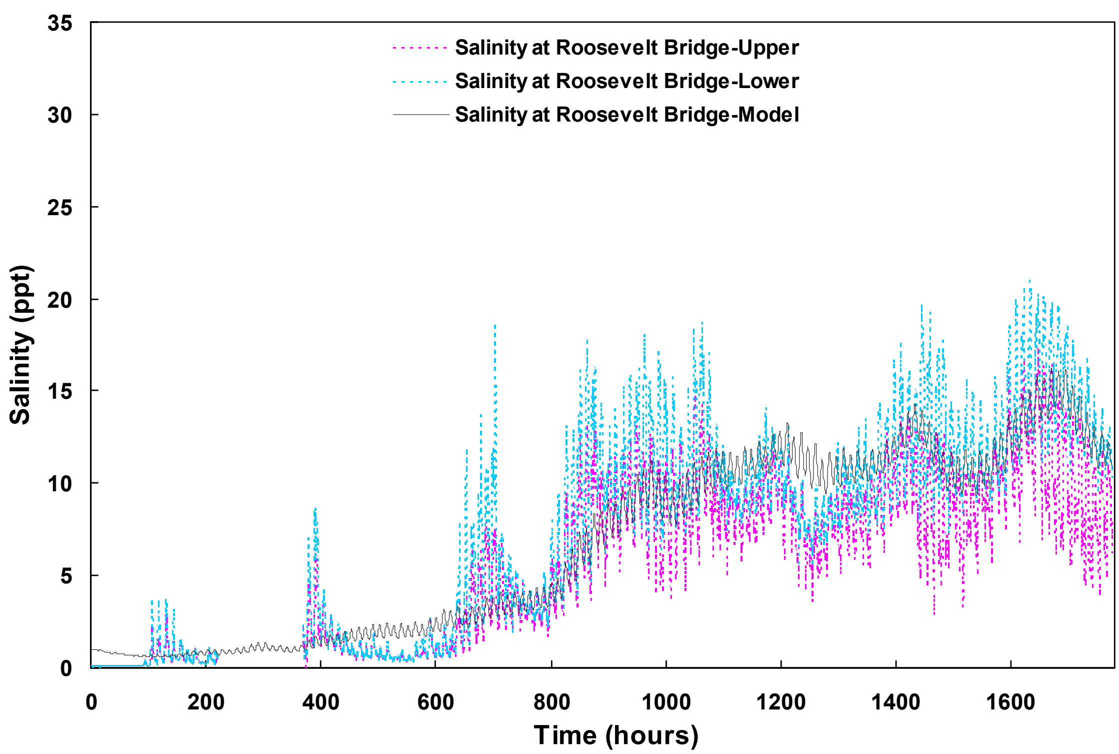


Figure F-12. Salinity at the Roosevelt Bridge

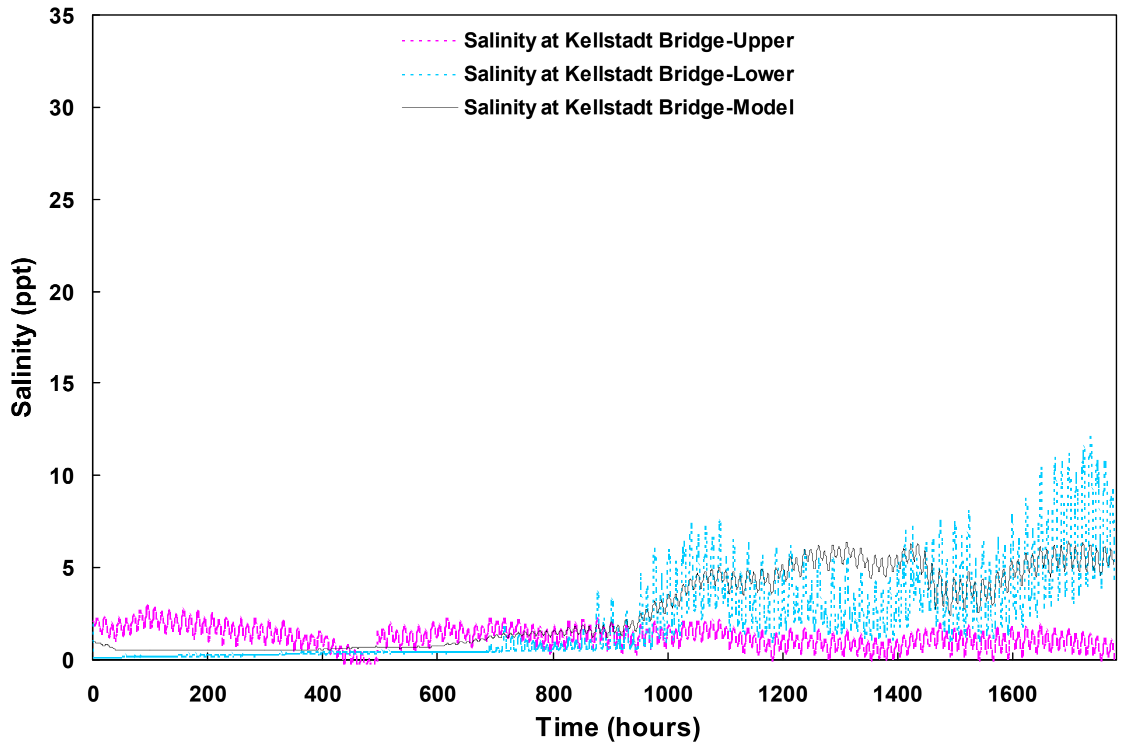


Figure F-13. Salinity at the Kellstadt Bridge

To evaluate the goodness-of-fit between model results and salinity data, the relative errors are calculated based on a daily average. The daily average was used because the discharge rates from inflow canals were measured daily. The calculation formula is as follows:

$$\text{relative error} = \frac{\text{daily averaged salinity result - daily averaged measurement value}}{\text{maximum of daily measurement value - minimum of daily measurement value}}$$

The relative errors are shown in **Table F-6**. The first 15 days are excluded to eliminate initial condition effects. Relative errors at the Roosevelt and A1A Bridges are normally in the range of 10 to 20 percent. At Kellstadt Bridge, the majority of relative errors are in the range of 10 to 20 percent except those between day 49 to 60. This might be caused by the inaccurate flow data from the North Fork during that period. In addition, a significant difference between the salinity monitoring data at the top and bottom layers was observed, indicating strong stratification (**Figure F-13**). Although simulation results fall in the middle of salinity data at the top and bottom layers, a three-dimensional model with fine bathymetry data on the North Fork will perform better than a two-dimensional model.

Table F-6. Relative Errors between Simulated Results and Monitored Data

	A1A Bridge			Roosevelt Bridge			Kellstadt Bridge		
Day	Model	Monitored	Relative Error	Model	Monitored	Relative Error	Model	Monitored	Relative Error
16	6.3	9.0	-0.16	1.1	2.3	-0.08	0.5	0.4	0.02
17	6.4	9.4	-0.19	1.4	3.3	-0.14	0.6	0.4	0.03
18	6.4	9.7	-0.20	1.5	1.7	-0.01	0.6	0.4	0.03
19	7.4	8.2	-0.05	1.7	1.1	0.04	0.6	0.4	0.04
20	7.6	7.1	0.03	1.8	0.9	0.07	0.7	0.4	0.04
21	8.0	11.0	-0.19	1.9	0.9	0.07	0.7	0.4	0.04
22	7.6	9.7	-0.12	2.0	0.7	0.09	0.7	0.4	0.04
23	7.4	7.4	0.00	2.0	0.5	0.10	0.7	0.5	0.04
24	8.1	7.7	0.02	2.0	0.7	0.09	0.7	0.5	0.04
25	8.8	11.0	-0.13	2.2	1.1	0.08	0.7	0.5	0.04
26	10.0	12.6	-0.16	2.5	1.1	0.10	0.8	0.4	0.06
27	9.2	10.4	-0.08	2.7	2.0	0.05	0.9	0.5	0.07
28	9.1	9.7	-0.04	2.7	3.9	-0.09	1.0	0.5	0.08
29	11.3	13.6	-0.14	3.0	5.9	-0.20	1.2	0.5	0.11
30	11.0	15.0	-0.24	3.4	6.0	-0.19	1.3	0.8	0.08
31	10.1	15.5	-0.33	3.5	4.0	-0.04	1.3	0.8	0.09
32	10.4	14.4	-0.25	3.6	3.3	0.02	1.4	0.7	0.11
33	10.6	13.4	-0.17	3.7	3.2	0.04	1.5	0.7	0.13
34	12.3	14.8	-0.16	4.1	4.7	-0.04	1.5	0.6	0.13
35	15.5	18.4	-0.18	5.0	6.7	-0.12	1.6	0.7	0.13
36	16.5	19.3	-0.17	6.2	9.2	-0.21	1.6	0.8	0.14
37	17.2	19.0	-0.11	7.1	9.9	-0.20	1.6	1.3	0.05
38	17.1	20.6	-0.22	7.8	9.3	-0.11	1.7	1.3	0.06
39	17.4	20.2	-0.17	8.4	9.7	-0.09	1.8	1.1	0.11
40	18.5	20.1	-0.10	9.2	10.7	-0.11	2.1	1.4	0.11
41	19.5	20.3	-0.05	9.8	10.5	-0.05	2.7	2.7	0.00
42	18.1	17.9	0.01	9.2	9.8	-0.04	3.0	2.8	0.04
43	18.6	18.1	0.03	8.9	10.0	-0.08	3.5	3.5	0.00
44	20.3	18.3	0.12	9.7	10.4	-0.05	4.2	4.6	-0.06
45	20.0	17.0	0.18	10.4	12.0	-0.11	4.5	4.6	-0.01
46	19.1	18.7	0.02	10.8	9.8	0.07	4.6	4.4	0.03
47	18.0	16.9	0.07	10.7	8.8	0.14	4.2	3.2	0.16
48	19.0	17.2	0.11	11.0	8.9	0.15	4.3	3.1	0.19
49	18.9	16.4	0.16	11.3	9.8	0.11	4.4	2.7	0.26
50	19.9	18.0	0.12	11.8	10.4	0.09	4.4	2.7	0.28
51	20.5	20.1	0.02	12.0	9.4	0.18	5.0	3.5	0.25
52	20.2	19.3	0.05	11.3	7.6	0.26	5.4	3.4	0.31
53	19.2	16.8	0.15	10.8	7.0	0.26	5.6	3.1	0.42
54	18.8	15.8	0.19	10.5	8.0	0.18	5.6	2.6	0.48
55	19.0	17.4	0.10	10.8	8.8	0.14	5.8	2.9	0.47
56	18.1	16.0	0.13	10.9	8.9	0.14	5.6	2.5	0.48
57	17.8	16.6	0.07	10.9	9.2	0.13	5.1	2.1	0.48
58	18.7	18.1	0.04	11.4	10.2	0.08	5.1	2.3	0.45
59	20.5	20.4	0.01	12.2	11.5	0.05	5.4	3.0	0.39
60	21.6	23.4	-0.11	13.2	11.4	0.13	5.8	3.8	0.32
61	19.2	20.2	-0.07	12.8	11.7	0.08	4.8	4.0	0.14

Table F-6. Relative Errors between Simulated Results and Monitored Data (Continued)

Day	A1A Bridge			Roosevelt Bridge			Kellstadt Bridge		
	Model	Monitored	Relative Error	Model	Monitored	Relative Error	Model	Monitored	Relative Error
62	18.3	18.4	-0.01	11.4	10.8	0.04	3.7	3.5	0.03
63	19.1	18.3	0.05	10.6	10.1	0.03	3.6	3.2	0.06
64	19.6	19.0	0.04	10.6	9.9	0.05	3.8	3.6	0.03
65	19.4	18.3	0.07	10.6	10.0	0.05	3.5	2.9	0.10
66	21.1	20.2	0.06	11.2	10.7	0.04	4.0	3.1	0.14
67	22.4	21.6	0.05	12.2	12.5	-0.02	4.6	3.7	0.14
68	23.0	21.8	0.07	13.2	13.6	-0.03	5.0	4.1	0.14
69	23.6	22.1	0.09	14.3	14.6	-0.03	5.4	5.0	0.06
70	23.2	20.7	0.15	14.9	13.7	0.08	5.5	5.6	-0.02
71	23.0	18.9	0.25	15.0	12.7	0.16	5.7	6.2	-0.09
72	21.6	17.3	0.26	13.7	12.0	0.13	5.6	6.3	-0.11
73	19.9	17.2	0.16	12.3	10.8	0.11	5.5	6.6	-0.18
74	19.2	17.4	0.11	11.6	10.3	0.10	5.4	6.4	-0.16
Average	**16.1**	**16.3**	**-0.03**	**8.2**	**7.8**	**0.06**	**3.2**	**2.4**	**0.17**

Application to the MFL Salinity Simulation

Based on the time periods when discharge was relatively stable, five prediction scenarios were selected for the 1995 Base Case and four were selected for the NSM. **Table F-7** and **Figure F-14** present the prediction scenarios for the 1995 Base Case. **Table F-8** and **Figure F-15** present the prediction scenarios for the NSM.

Table F-7. Prediction Scenarios Selected for the 1995 Base Case

Julian Day	27-42	95-105	19-24	74-79	112-117
Discharge (cfs)	235	130	80	35	25
Miles Upstream from Kellstadt Bridge	-1.5	2.5	3.5	10.5	13.4

Table F-8. Prediction Scenarios Selected for the NSM

Julian Day	34-50	52-60	10-30	112-119	34-50
Discharge (cfs)	120	100	80	20	120
Miles Upstream from Kellstadt Bridge	0	0.5	4.5	13.5	0

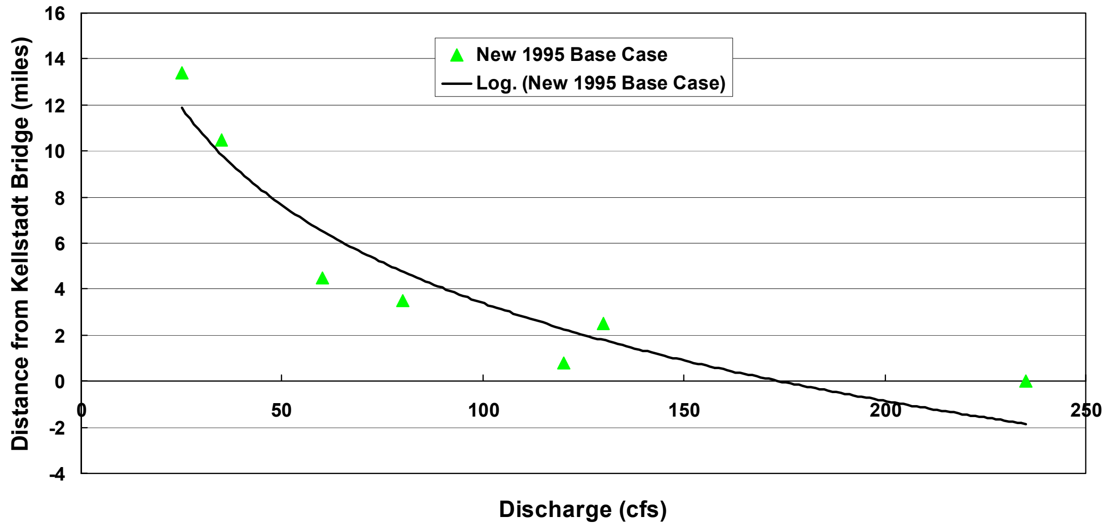


Figure F-14. Location of the 5-ppt Isohaline Zone in the 1995 Base Case Simulation

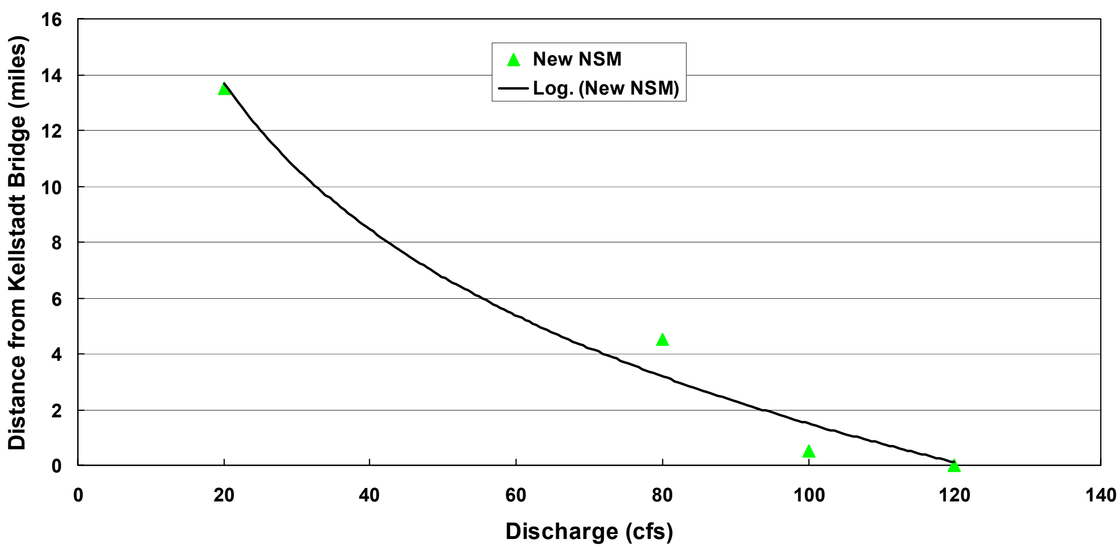


Figure F-15. Location of the 5-ppt Isohaline Zone for the NSM Simulation

According to the prediction results, the relationship between the location of the 5-ppt isohaline zone and the discharge rate can be described as follows:

$$L = -6.1 \ln(Q_f) + 33.1 \qquad \text{1995 Base Case}$$

$$L = -7.6 \ln(Q_f) + 37.9 \qquad \text{NSM}$$

When discharge is larger than 175 cfs for the 1995 Base Case, the 5-ppt isohaline zone is downstream of Kellstadt Bridge on the North Fork of the St. Lucie River.

Summary

The hydrodynamic and salinity simulations used to determine and monitor MFLs can be further improved with more accurate inflow and bathymetry data. For the most part, a three-dimensional model will work best. Prediction of the location of the 5-ppt isohaline zone for the North Fork should be conducted with a two-dimensional RMA model.

APPENDIX G
CURRENT PROJECTS ASSOCIATED WITH THE INDIAN RIVER LAGOON SWIM[1] PROGRAM

Project Name	Description	Funding Mechanism
BASIN STUDY AND ASSESSMENT		
Watershed		
Manatee Pocket Study	Study of Manatee Pocket storm water inflows and recommendations for treatment	SWIM
Survey Work for HSPF	Cross-sections of the C-24 Canal and the South Fork of the St. Lucie River will be surveyed to support Hydrologic Simulation Program FORTRAN (HSPF) analyses	
C-24/North St. Lucie Basin Assessment	Basin assessment for the C-24 and North St. Lucie basins	
Martin County GIS	Geographic Information Systems (GIS) work to support a storm water management program	SWIM
NRCS Co-Op Study	Monitoring Floridan water use in cooperation with the Natural Resources Conservation Survey (NRCS)	
St. Lucie River Watershed Assessment	Assessments of the C-25,C-23,C-44, and Tidal St. Lucie basins, and Basins 1, 4, 5, and 6	
Kitching Creek Headwaters Water Quality Improvement	Two part study to 1) evaluate alternative plans; and 2) develop a detailed engineering design for improving the quality, flow, and timing of water into Kitching Creek	
Nutrient Load Monitoring		SWIM
RESEARCH		
Estuary		
Indian River Lagoon and St. Lucie Estuary Monitoring	Water quality monitoring network in the Indian River Lagoon and the St. Lucie Estuary	
Manatee Pocket Sediment Study	Treffrey/FIT study of sediments in Manatee Pocket	
Turbidity/Sea Grass Study	Ecological characteristics and maximum growth of sea grasses at a location experiencing colored water discharge and a location removed from the discharge near Fort Pierce	
Aerial Photographs	Aerial photographs for preparing sea grass maps	
Muck Removal Demonstration Project	Evaluate feasibility of removing muck sediments from the St. Lucie Estuary	
PAR Study	Smithsonian PAR calibration	
Indian River Lagoon Sea Grass Transects	Monitoring two times a year of 6 transects that were installed in September 1994 from Jupiter to St. Lucie Inlet	
Indian River Lagoon Sea Grass Transects - additional monitoring	Additional monitoring of the Indian River Lagoon Sea Grass Transects was done in May 1998 due to Lake Okeechobee regulatory releases	
Sea Grass Mapping	Mapping sea grass lagoonwide from aerial photos and ground truthing	
Indian River Lagoon Bathymetry	Two-year contract to develop Indian River Lagoon bathymetry	

1. SWIM = Surface Water Improvement and Management

Project Name	Description	Funding Mechanism
St. Lucie Estuary Monitoring Network	Monthly monitoring of St. Lucie Estuary network that was revised in 1997 (monthly instead of every 2 weeks; fewer stations)	
St. Lucie Estuary Nutrient Loading Monitoring	Nutrient/sediment loading monitoring within the C-23, C-24, C-25, and C-44 Canals and Five and Ten Mile Creeks	
Aerial Photographs	Aerial photographs for preparing sea grass maps	
Indian River Lagoon Monitoring Network Evaluation	Forty stations monitored quarterly	
Indian River Lagoon Sea Grass Map and Photography	Aerial photographs of the entire lagoon, mapping of sea grasses from photos and ground truthing	SWIM
Sea Grass Data Summary	Trend analysis of sea grass maps; summary of transect data; recommendations for future monitoring - particularly for St. Lucie Estuary Pollutant Load Reduction Goal (PLRG) development	
St. Lucie Initiative Muck	The St. Lucie River Initiative will explore ways to demuck and find beneficial reuse for muck.	
Environmental Toxicity in St. Lucie Estuary/Indian River Lagoon		St. Lucie River Issues Team
Pesticide Reconnaissance within the St. Lucie Estuary		St. Lucie River Issues Team
Watershed and Aquatic Research Assessing Key Environmental Issues in the St. Lucie Estuary		St. Lucie River Issues Team
Fish Health Problems in the St. Lucie Estuary		St. Lucie River Issues Team
St.Lucie Estuary Water Quality		St. Lucie River Issues Team
Watershed		
Distribution of Oysters and Submerged Aquatic Vegetation in the St. Lucie Estuary	Past, current, and future distribution of oysters and submerged aquatic vegetation in the St. Lucie Estuary	
Agrochemical and Nutrient Loadings in the St. Lucie Estuary basin	Characterization of agrochemical and nutrient loadings in runoff from pastures, golf courses, and urban areas in the St. Lucie Estuary basin and nitrogen, phosphorus, and metals from citrus and Vegetables	St. Lucie River Issues Team
Nutrient and Metal Loading in the Indian River Area	Characterization of nitrogen, phosphorus, and heavy metals in surface water runoff from citrus groves and vegetable fields in the Indian River Area	St. Lucie River Issues Team
Water Table Management BMP	Use water table management as a best management practice (BMP) for reducing discharges from Indian River citrus groves	St. Lucie River Issues Team
Citrus and vegetable water quality		St. Lucie River Issue Team
Citrus pesticide BMP		St. Lucie River Issue Team
Golf, urban, pasture water quality		St. Lucie River Issue Team
Indian River Citrus BMPs for equipment operator and applicators		Center for Environmental Studies contract number 56
Virginia Avenue Retrofit - Event Monitoring		
Water Quality/Sediment Monitoring		

Project Name	Description	Funding Mechanism
Watershed Agricultural BMPs	Implementation of BMPs in citrus and vegetable cropping systems in the St. Lucie Estuary and Indian River Lagoon region. This effort will document, demonstrate, and implement BMP effectiveness at improving surface water quality through the reduction of nitrogen and phosphorus.	
EXOTIC REMOVAL		
Watershed		
Exotic Removal – Savannas		Local, SWIM, and SFWMD
North Fork Exotics		SWIM/Water Management Lands Trust Fund
HABITAT RESTORATION		
Estuary		
Mosquito Impoundment Restoration	Restoration of FOS impoundment	
Mosquito Impoundment Restoration	Restoration (culverts, aerators, and pumps) in impoundments: 1-9, 10A, 12, 16A, and 17A	
Mosquito Impoundment Restoration	Restoration (culverts and pump upgrades) in impoundments 5, 9, and 16A	
Mosquito Impoundment Restoration	Restoration (culverts, pump, and aeration station; lengthen 2 pumps) of impoundment 14B; begin restoration of 10A (40-foot vinyl seawall; 4 flowways)	
Mosquito Impoundment Restoration	Impoundments 2, 5, 10A, and others; wading bird study, topographical survey, pump upgrades, and extension; aerator upgrades, convert to dual pump stations, weir, and 2 culverts	
Indian River Lagoon Florida Department of Environmental Protection (FDEP) Mosquito Impoundment Restoration		
Indian River Lagoon Mangrove Planting	Continue experimental mangrove planting technique (year 3); identify biodegradable materials; evaluate success of first two years of program	SWIM
Indian River Lagoon Wetland Restoration	Reconnect isolated tidal wetlands to lagoon; create tidal pools; plant native species on Bureau of Land Management land near the Jupiter Inlet	SWIM
Indian River Lagoon/SLCMCD Mosquito Impoundment	Continue restoration efforts in impoundments 5, 6, and 7	
Mosquito Impoundment Report	Summary of past, current, and future mosquito impoundment restoration projects for SWIM plan update	
North Fork Restoration		St. Lucie River Issue Team
Oyster Restoration		St. Lucie River Issue Team
Martin County Mosquito Control Impoundment Reconnects	Martin County Mosquito Control will reconnect 4 impoundments on the FOS site	
Indian River Lagoon Mangroves - Habitat Restoration		SWIM/Water Management Lands Trust Fund
Indian River Lagoon Snook Tag - Habitat Restoration		SWIM/Water Management Lands Trust Fund

Project Name	Description	Funding Mechanism
Mosquito Impoundment Restoration	Restoration of mosquito impoundments along the Indian River Lagoon and St. Lucie Estuary in both Martin and St. Lucie Counties for habitat and water quality improvements	
Mosquito Reconnection - Habitat Restoration		SWIM/Water Management Lands Trust Fund
TNC Shoreline Restoration		SWIM/Water Management Lands Trust Fund
Watershed		
Mechanical Harvesting Contract	Removing floating aquatic weeds with conveyor belt machinery	
Snook License Plate	10 habitat restoration and environmental education projects	
North Fork Exotic Vegetation Removal	Removal of exotic vegetation on the North Fork of the St. Lucie River	
Sim's Creek Habitat Restoration	Exotic removal, shoreline revegetation, and wetland creation	
Snook License Plate	13 Habitat Restoration and Environmental Education Projects	
Snook License Plate	Habitat Restoration and Environmental Education Projects	
North Fork Habitat Restoration	Restore function of the marshes along the North Fork of the St. Lucie River; reconnection of isolated mangrove marshes would provide acres of habitat, water attenuation, and quality enhancement.	
STORMWATER TREATMENT AREAS		
Watershed		
C-44 Stormwater Treatment Area		St. Lucie River Issue Team

APPENDIX H THE APPLICATION OF THE ST. LUCIE ESTUARY HYDRODYNAMICS/SALINITY MODEL IN THE INDIAN RIVER LAGOON AND ST. LUCIE ESTUARY ENVIRONMENTAL STUDY

Gordon Hu, SFWMD

AREA OF MODEL COVERAGE AND DATA COLLECTION SITES

The St. Lucie Estuary hydrodynamics/salinity model covers the entire St. Lucie Estuary and a portion of Indian River Lagoon (**Figure H-1**). The model domain includes the North and South Forks of the St. Lucie River, the middle and lower St. Lucie Estuary, the St. Lucie Inlet, and the Indian River Lagoon between Nettles Island and Pecks Lake.

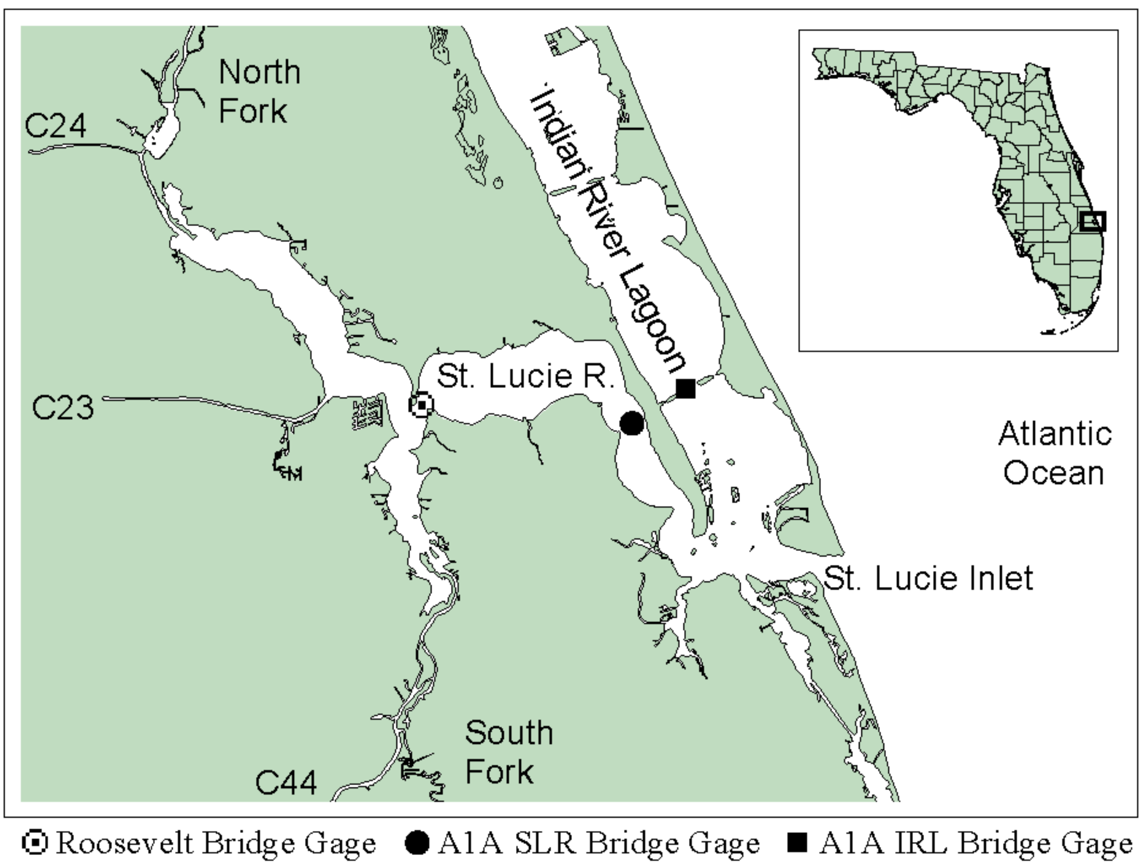


Figure H-1. Model Domain and Locations of Tide/Salinity Data Collection Stations

Tide/salinity stations were installed in the St. Lucie Estuary in early 1997. The locations of three stations are shown in **Figure H-1**. Since August 1997, these stations have recorded more then three years' worth of data. Tide (water surface elevation), currents (flow velocity), salinity, and temperature are recorded continuously at 15 minutes intervals. Salinity and temperature are measured at two different depths to detect stratification in the water column. The data can be retrieved through satellite with approximately four hours lag time. After the model verification was completed in early 1999, the stations have mainly served as monitoring stations. The near real time data provided first hand information for environmental assessment and operational planning. The data collection program was extended in January 1999 when five more tide/salinity stations were installed in the Indian River Lagoon between the Fort Pierce Inlet and Pecks Lake.

MODEL DESCRIPTION

The St. Lucie Estuary hydrodynamics/salinity model is a two-dimensional finite element model (Hu, 1999). The model was developed to assess the impact of drainage canal discharge and storm water runoff. The model also provides hydraulic information for water quality study and modeling. **Figure H-2** is the finite element mesh of the model. Both triangular and quadrilateral elements are used in the mesh to fit the complex shoreline. In order to establish a more stable salinity boundary condition (Hu and Unsell, 1998), the model mesh was extended approximately 6 miles off shore into the Atlantic Ocean. The model geometry is based on a bathymetric survey conducted in 1998. Portions of major drainage canals were included in the model mesh using single line of quadrilateral elements.

The model computes tides (water surface elevation), two-dimensional velocity field, and salinity distribution in the model domain. The United States Army Corps of Engineers' RMA 2 model was used for hydrodynamics and RMA 4 was used for salinity simulation. Since the main interest of this study is in the impact of watershed runoff on the overall salinity regime in the estuary, a two-dimensional depth averaged approach was considered sufficient. For water quality study at the next stage, the model will be converted to a three-dimensional version.

MODEL VERIFICATION

Tidal boundary conditions were generated using a tidal constituent database developed by the Waterways Experiment Station of the United States Army Corps of Engineers. Canal and tributary discharges were based on field measurements and a watershed runoff model, the Hydrologic Simulation Program - FORTRAN (HSPF).

The model was first tested against National Ocean Service tidal data. Mean tidal range of the model output was compared with National Ocean Service data and had a margin of error less than 5 percent.

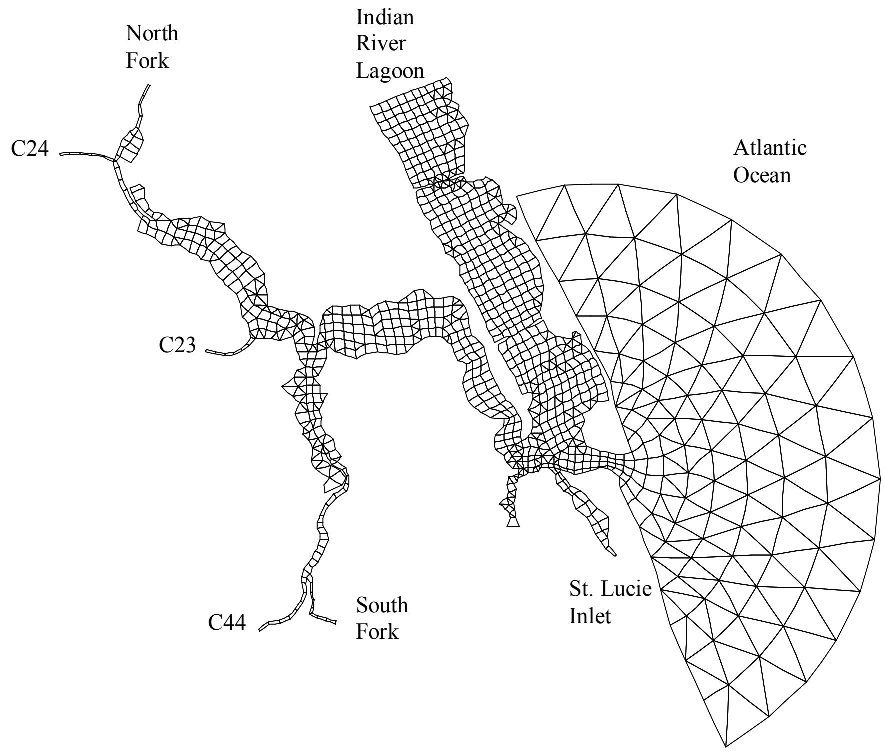


Figure H-2. Finite Element Mesh of the St. Lucie Estuary Model

The model was further applied to the 1997 to 1998 ENSO episode. Tidal data and salinity data collected from November 1997 through June 1998 were used in model sensitivity analysis and verification. **Figures H-3** and **H-4** compare model output with field data. The field measurements were taken at two different depths to reflect any possible stratification. For most of the model testing period, the salinity records showed a clear salinity stratification with a low salinity layer (fresh water) at the surface. The model output is depth-averaged salinity. Therefore, it falls between the two field measurements.

IMPACT OF CANAL DISCHARGE ON THE ESTUARINE SALINITY

Drainage canal discharge has a major impact on the salinity condition in the estuary. The estuary model was applied to various freshwater inflow conditions to establish a relationship between the magnitude of freshwater inflow and the estuary salinity. Thirty-three model simulations were conducted with eleven different freshwater inflows at 300 cubic feet per second (cfs), 500 cfs, 700 cfs, 1,000 cfs, 1,300 cfs, 1,600 cfs, 2,000 cfs, 2,500 cfs, 3,000 cfs, 5,000 cfs, and 10,000 cfs. This covers the full range of freshwater inflow found in historic records. The freshwater inflow included both surface and subsurface (ground water) input to the estuary. Ocean tidal boundary condition for these simulations are monthly tides with two spring tides and two neap tides. The model output was used to create eleven salinity contour maps presenting the spatial distribution of salinity for each level of freshwater input. The color plate attached to this document is a

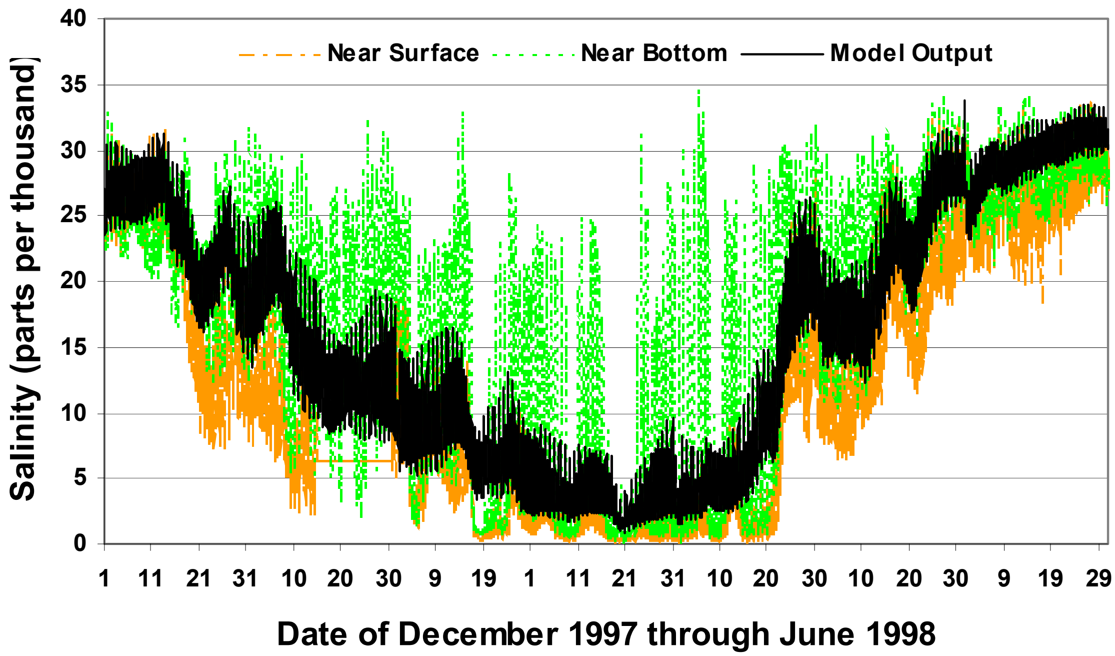


Figure H-3. Model Verification at the A1A Bridge Station in the Lower Estuary

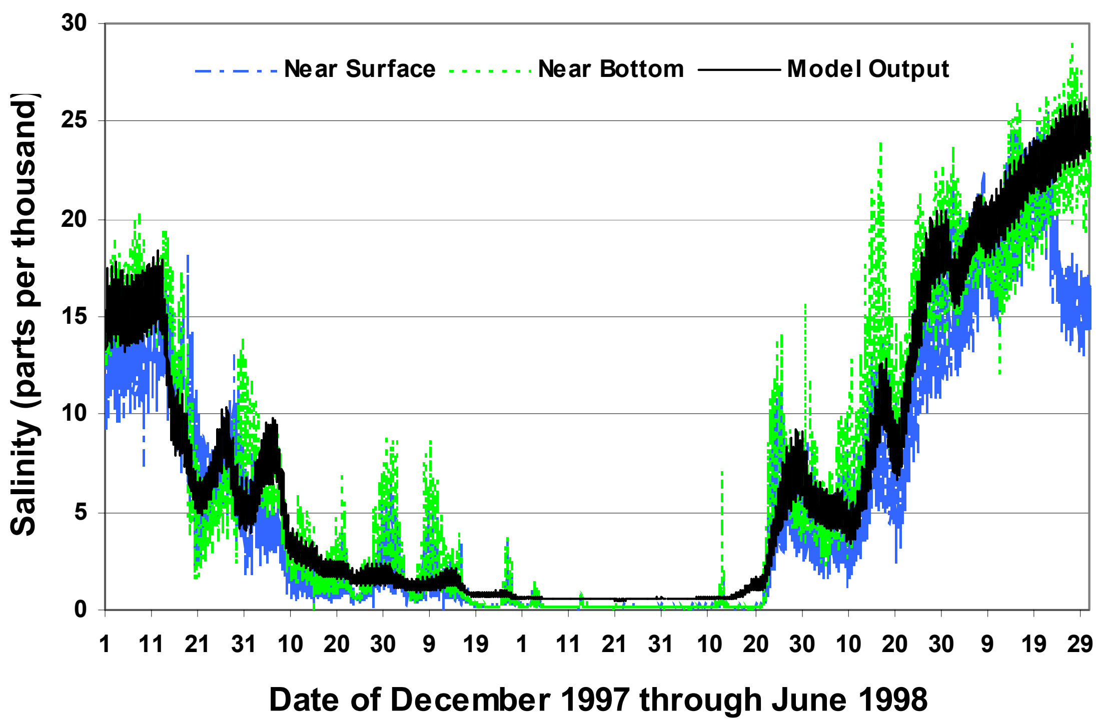


Figure H-4. Model Verification at the Roosevelt Bridge Station in the Upper Estuary

mosaic of six salinity contour maps that show the trend of salinity declining when fresh water inflow increases.

The model simulations indicate that when total freshwater inflow reaches the 2,000 to 3,000-cfs level, the upper estuary will be dominated by fresh water and salinity in the area will remain close to zero even during high tide. The extent of freshwater domination depends on the magnitude of freshwater inflow. If total inflow reaches 10,000 cfs, the zero salinity zone will extend to the A1A bridge and Hellgate in the lower estuary. Since the data collection program began in 1997, several major storm events and high regulatory releases have occurred. The salinity records obtained in these events confirmed that the model prediction of inflow/salinity relationship was accurate.

For quick reference, two salinity profile charts were created that describe the salinity gradients from the St. Lucie Inlet up to the South and North Forks (**Figures H-5** and **H-6**, respectively). Each line in **Figure H-5** represents the longitudinal salinity gradient from St. Lucie Inlet to the junction of the C-24 Canal and the North Fork. Each line in **Figure H-6** represents the longitudinal salinity gradient from the junction of the C-44 Canal to the old South Fork.

To find the salinity gradient for a freshwater discharge that falls between any two of the eleven flow levels, linear interpolation can be used. Since the salinity difference between the adjacent lines in the chart is less than 5 parts per thousand (ppt), the error in interpolation should be less than 1 to 2 ppt.

The flow-salinity relationship charts were used to assist decision making in system restoration/operation planning. Given the magnitude of total freshwater inflow, the likely resulting salinity gradients/distribution in the estuary can be found in the charts and salinity contour maps.

The computations were based on the assumption of constant, uniformly distributed, runoff discharge. These charts were intended for quick, preliminary assessment purposes. If more detailed, accurate predictions are required, it is necessary to conduct dynamic model simulations with flow/tide boundary condition input.

LONG-TERM SALINITY COMPUTATION

A utility computer code was developed by SFWMD to facilitate the need for long-term salinity computations in alternative evaluations. Based on simulations using this code with various freshwater inflows, a flow-salinity relationship was established for several locations in the estuary. **Figure H-7** presents the flow-salinity relationship for Station SE03 located at the US 1 (Roosevelt) Bridge in the upper estuary. **Figure H-8** presents the flow-salinity relationship for Station 01 located at the A1A Bridge near Hellgate in the lower estuary.

While the salinity levels in the charts represent the equilibrium state with steady freshwater inflow, in reality, freshwater inflow is rarely constant. The salinity condition observed in the estuary is the result of a series of transitions from one state to the next. Therefore, the change in salinity always lags behind the flow change. **Figure H-9** is an example of such a transition at Station SE03.

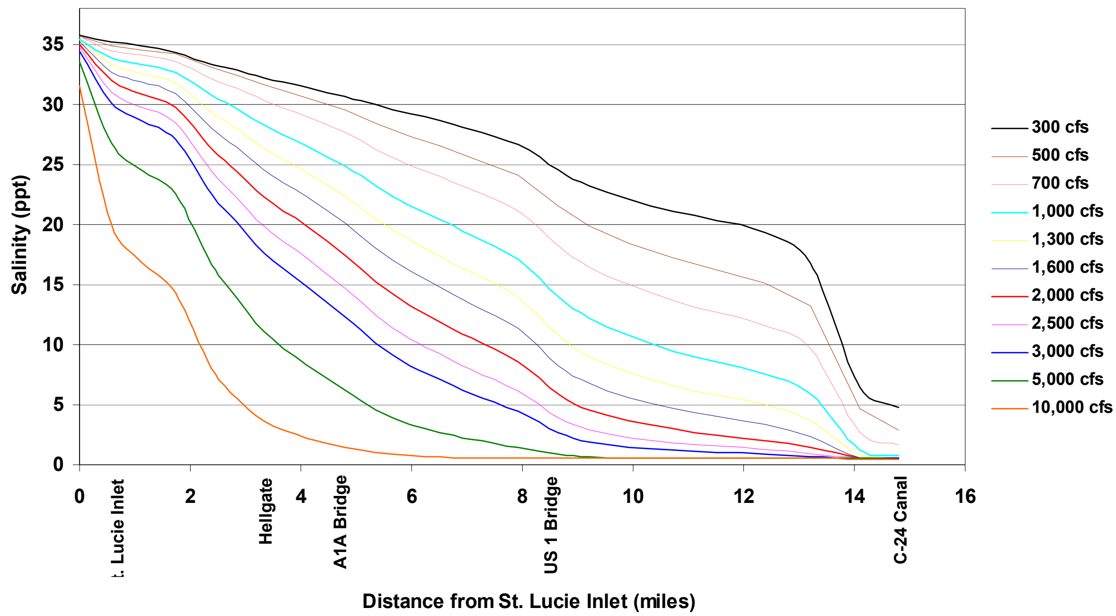


Figure H-5. Model Predicted Salinity Conditions at Various Magnitudes of Freshwater Inflow from the St. Lucie Inlet to the North Fork

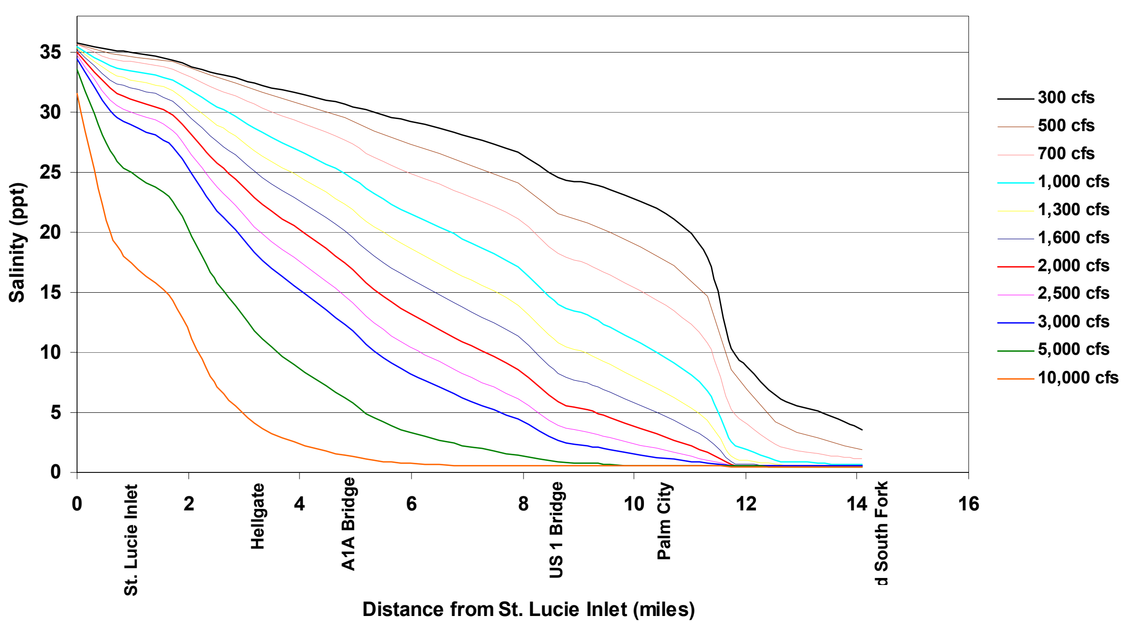


Figure H-6. Model Predicted Salinity Conditions at Various Magnitudes of Freshwater Inflow

Data has been collected at the tide/salinity stations deployed in the estuary for more than 3 years, beginning in August 1997. When canal discharge changes, the salinity changes occur accordingly. Based on the observation of several dozen such events in the past few years, it appears that a large portion of salinity transition occurs within a week,

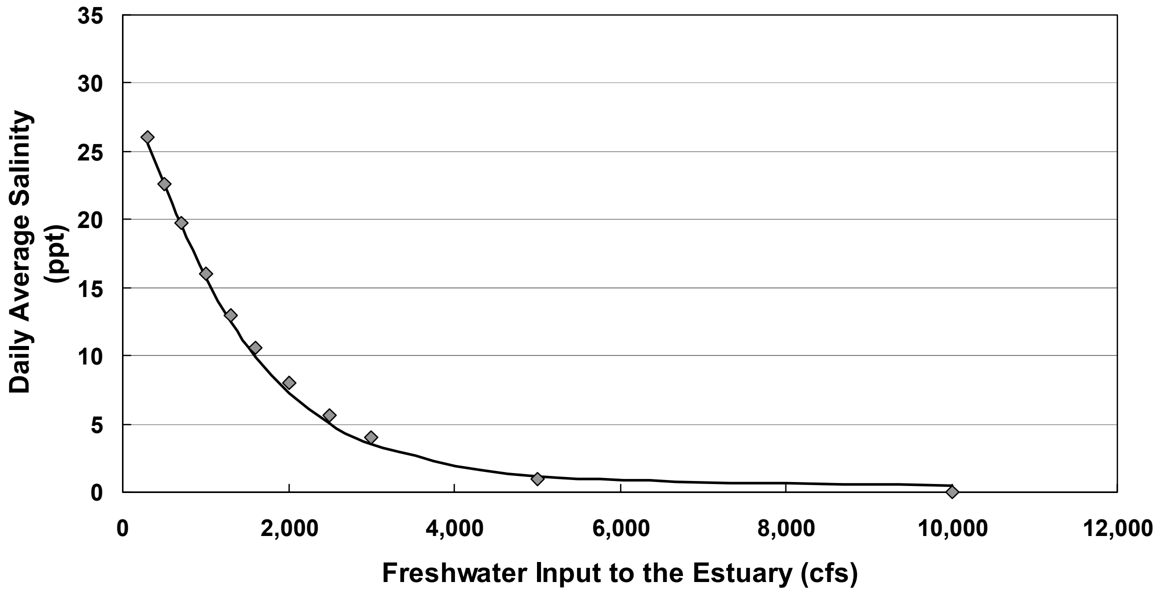


Figure H-7. Salinity-Flow Relationship at the Roosevelt Bridge in the Upper Estuary.

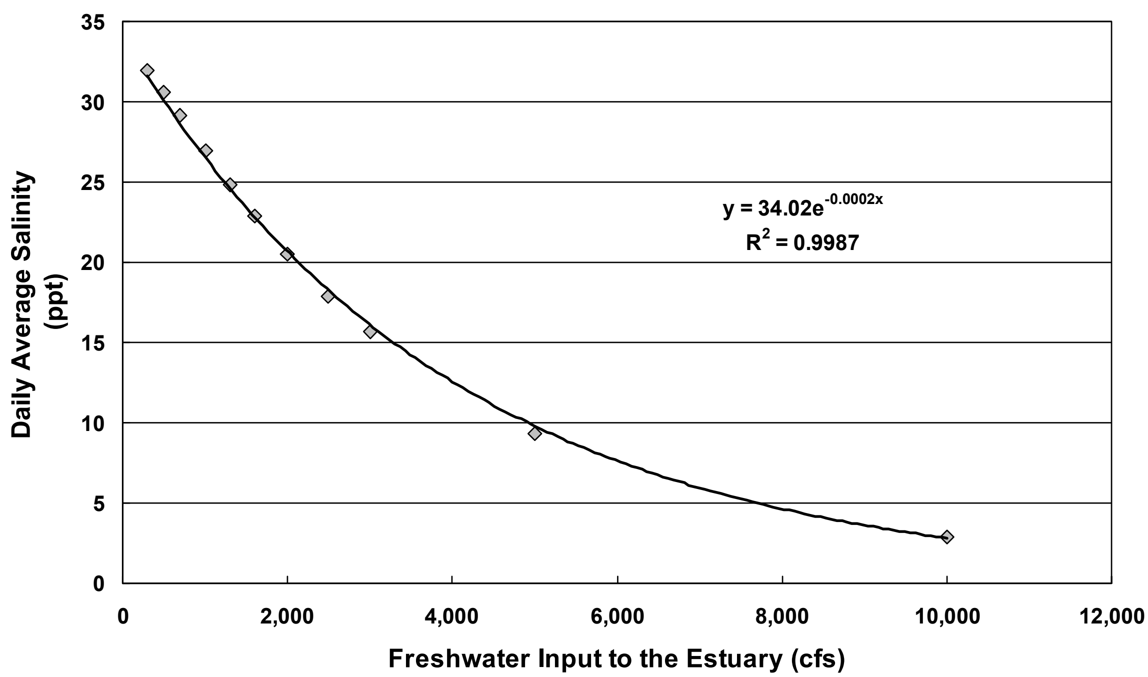


Figure H-8. Salinity-Flow Relationship at the A1A Bridge at Hellgate in the Lower Estuary

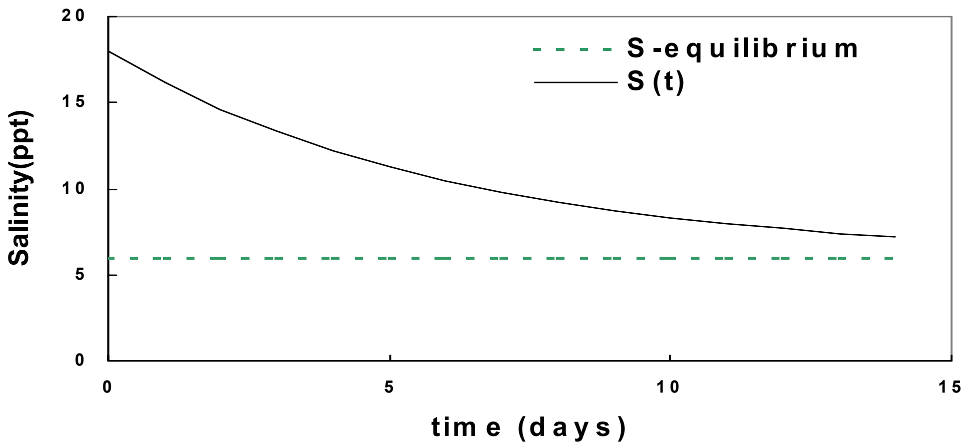


Figure H-9. Salinity Regime Transition at Station SE03

but it takes approximately two weeks for complete transition. This observation was consistent with the salinity model prediction.

Both field observation and model simulation indicate that estuary salinity displays of a series of transitions from one quasi-equilibrium condition to another. A utility computer code was developed based on this concept. Both field data and model output were analyzed to establish the transition time and freshwater inflow-salinity relationship for stations in the estuary. The computer program first calculates the potential target (equilibrium) salinity based on the magnitude of freshwater inflow. Then it calculates the salinity change on daily time steps. Taking into account both target salinity and the initial salinity condition. If further freshwater inflow change occurs before the transition is complete, then a new transition begins and the program repeats the same computational procedure for the new transition.

Figures H-10 and **H-11** are the testing output of the utility code. The output was compared with real data at two salinity stations in the estuary. Since the utility code operates on daily time steps, the model output is a daily-averaged value that does not depict the daily variation due to high and low tides. The testing case includes one of the highest regulatory releases ever made through the C-44 Canal. The salinity regime experienced extreme changes during that time period. The utility computer program performed well under these extreme events and the model output matched the field records closely.

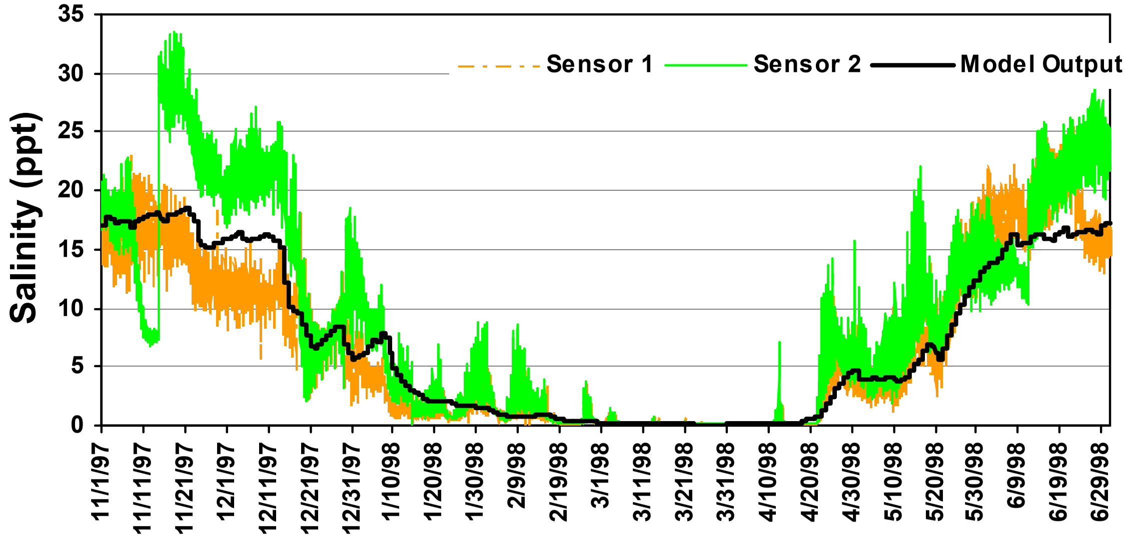


Figure H-10. Results of Long-Term Simulation Testing at the Roosevelt Bridge in the Upper Estuary.

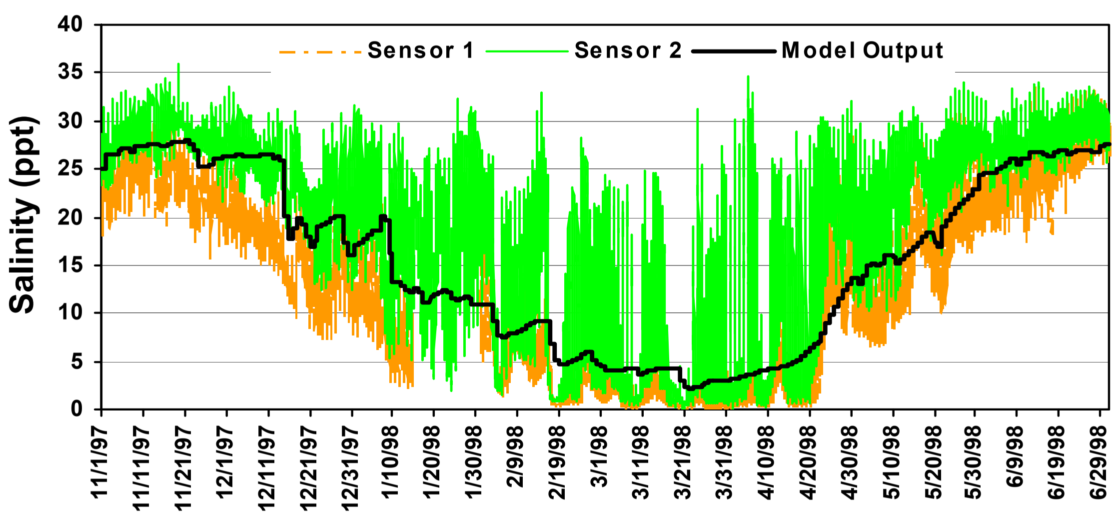


Figure H-11. Results of Long-Term Simulation Testing at the A1A Bridge in the Lower Estuary.

SALINITY COMPUTATIONS UNDER HISTORIC (NATURAL), PRESENT, AND FUTURE WITH PROJECT CONDITIONS

To evaluate plans for watershed management and drainage canal operations, salinity computations were conducted under the following four scenarios:

- Scenerio 1 - 31-year period simulation under 1995 Base Case conditions
- Scenerio 2 - 31-year period simulation with output from the Natural Systems Model (NSM) (**Figure H-12**)
- Scenerio 3 - 31-year period simulation with assumed predevelopment land use (mostly forest and wetland)
- Scenerio 4 - 31-year period simulation with a proposed watershed management plan (**Figure H-13**)

The purpose of Scenerios 2 and 3 was to establish natural salinity conditions in the predevelopment era. Model output indicates that the salinity in the estuary was more stable under natural conditions than present conditions. The model output with the proposed watershed management plan predicts that the occurrence of extremely low salinity levels will be less frequent than current conditions.

Figures H-12 and **H-13** contain a huge amount of information drawn from simulations over a 31-year time series. The differences between scenarios would be difficult to read from such condensed charts. The intention of this memo is to provide an outline of the St. Lucie Estuary hydrodynamics/salinity model and its applications in Indian River Lagoon and St. Lucie Estuary study. More detailed analysis on the results of these simulations could be found in other reports of this project.

MODEL ASSUMPTIONS AND LIMITATIONS

The freshwater inflow-salinity relationship includes both surface and subsurface (ground water) input to the system. When generating freshwater input for model simulations, both surface and subsurface hydrology should be included.

The model is two-dimensional with depth averaged. Therefore, the model does not simulate the stratification in the water column. While depth averaged salinity is sufficient to describe the overall salinity regime on a macro scope, it does not reflect the salinity difference between the surface layer and the bottom layer when the system is stratified. For biological study, it is necessary to consider the factor of stratification. According to the current work plan, the model will be converted to a three-dimensional version in the near future.

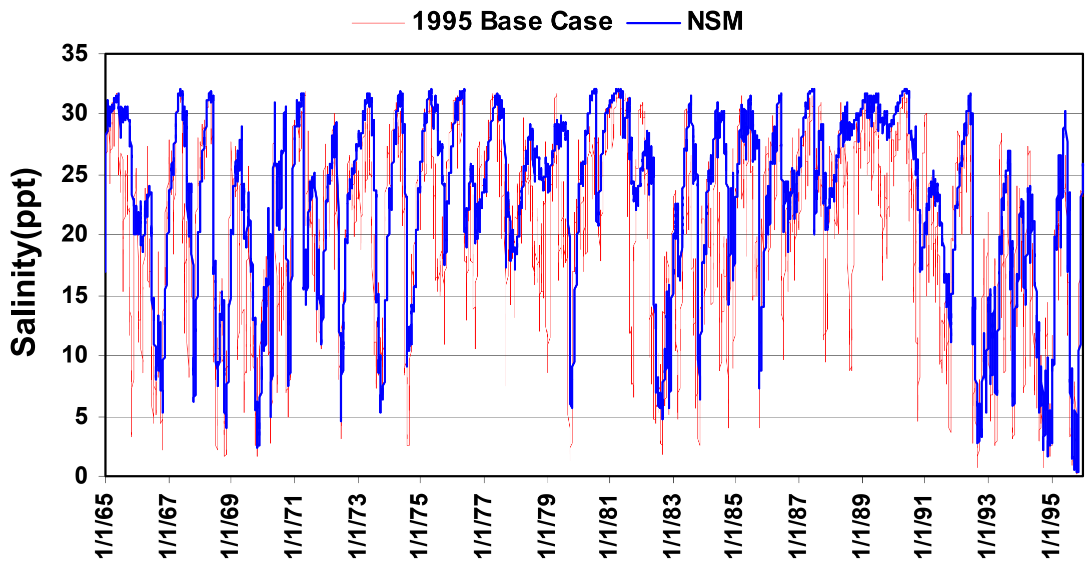


Figure H-12. Natural (NSM) versus Present (1995 Base Case) Conditions Salinity at the Roosevelt Bridge

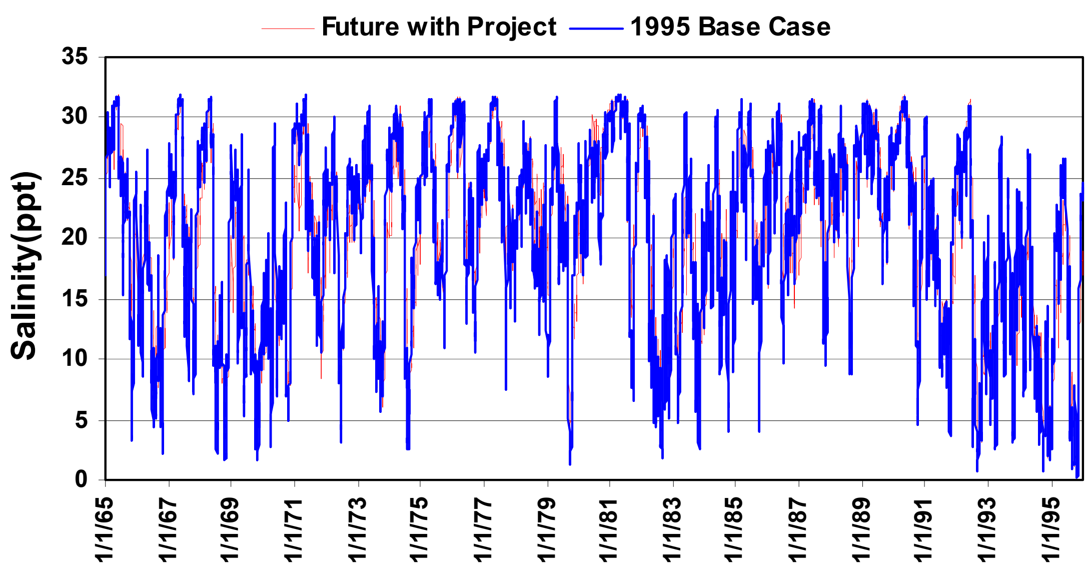


Figure H-13. Future with Project versus Present (1995 Base Case) Conditions Salinity at the Roosevelt Bridge

REFERENCES

Hu, G. 1999. Two-dimensional Hydrodynamic Model of St. Lucie Estuary. In: *Environmental Engineering 1999*, *Proceedings of the ASCE-CSCE National Conference on Environmental Engineering*, American Society of Civil Engineers, pp 434-443.

Hu, G., and Unsell, D. 1998. Tidal Circulation in the Southern Indian River Lagoon. In: *Water Resources Engineering'98*, *Proceedings of the International Water Resources Engineering Conference* 1:844-849, American Society of Civil Engineers.

APPENDIX I
SCIENTIFIC PEER REVIEW PANEL FINAL REPORT AND DISTRICT RESPONSE

FIRST DRAFT
FINAL REPORT

By:

THE TECHNICAL DOCUMENTATION TO SUPPORT DEVELOPMENT OF MINIMUM FLOWS FOR THE ST. LUCIE RIVER AND ESTUARY SCIENTIFIC PEER REVIEW PANEL

To:
South Florida Water Management District
Water Supply Division
P.O. Box 24680
West Palm Beach, Florida 33416-4680

Panel Chair, Report Editor:

Mark S. Peterson, Ph.D.
Department of Coastal Sciences
College of Marines Sciences
The University of Southern Mississippi
703 East Beach Drive
Ocean Springs, Mississippi 39564

Panel Members:

Edward J. Buskey, Ph.D.
The University of Texas at Austin
Marine Science Institute
750 Channelview Drive
Port Aransas, Texas 78373

Wu-Seng Lung, Ph.D., P.E.
School of Engineering and Applied Science
The University of Virginia
Thornton Hall
Charlottesville, Virginia 22903-2442

July 10, 2001

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report is an independent peer review of the scientific and technical data and methodologies supporting the minimum flows and levels (MFL's) of 21 cfs for the North Fork and 7 cfs for the South Fork of the St. Lucie River and Estuary (SLE) outlined in the "Draft Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary" published on 21 May 2001 (SFWMD, 2001). Flows less than these suggested MFL's would cause "significant harm" to the SLE. The Draft Technical Document describes the SLE, the process and basis for establishment of minimum flows and levels, legal and policy issues, and definitions of levels of "harm". A small number of other appropriate documents were provided by the District for consideration by the expert panel. The peer review panel was charged to review the document on its technical basis of MFL criteria only, policy decisions and assumptions were not subject to peer review. Based on the panel's review, the criteria and data used by the District was the best available information at the time of the report. Two major issues surfaced with the expert panel: 1) salinity model development and validation, and 2) connection of the oligohaline zone and the VEC.

Overall, the data and approaches to analyzing the data and the modeling are scientifically valid. However, salinity data are needed to support the hydrodynamic modeling effort since no salinity data from the study area are presented in the Draft Technical Documentation. It is recommended that additional modeling results of salinity be presented in the Final Technical Documentation to document model calibration using available salinity data. Quantitative assessment of the goodness-of-fit between the model results and salinity data must be included. There is no mention of the linkage between the watershed model and the hydrodynamic model in the Draft Technical Documentation. An ideal simulation scenario to fully validate the hydrologic and hydrodynamic model simulations would be to perform a 10-year simulation to reproduce the long-term salinity data from 1989 to 1999. Salinity data are available from the SWIM program for the SLE. The most serious ecological deficiencies in this plan are the lack of direct evidence connecting the oligohaline zone to tangible evidence of enhancement of VEC's and the lack of consideration of other potential benefits, such as nutrients and organic matter. These are associated with the freshwater inflows to the estuary and may be required to maintain estuarine productivity. These deficiencies are not associated with any flaws in the proposed minimum flow criteria, but are simply due to a lack of information on this particular estuarine system.

The process of adaptive management requires a clear management goal (such as, maintaining a certain area or volume of oligohaline habitat during certain seasons), monitoring (which can be restricted to the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and re-evaluation of the MFL's on short-term intervals. Without knowing how much (or when) oligohaline habitat is required to maintain or enhance productivity in the SLE, there is no clear, compelling minimum flow rate. Therefore, setting the management goal will require evaluation of the biological communities and environmental setting, and policy decisions on which natural resources are to be conserved, protected, or optimized. Monitoring could be economical because the main variables of interest (salinity and DO) are inexpensive to measure and are automated This focused monitoring activity would allow for annual evaluation and refining of the MFL's

INTRODUCTION

Purpose

The purpose of this report is to present findings of an independent scientific peer review of the scientific and technical data and methodologies supporting the proposed MFL for the St. Lucie River and Estuary published on 21 May 2001 by the South Florida Water Management District ("District"). Specifically, we reviewed a scientific report prepared by the District entitled "Draft Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary" (SFWMD, 2001). The technical report was accompanied by copies of a number of its key supporting references. An independent peer review is defined by Florida Statutes to mean the review of scientific data, theories, and methodologies by a panel of independent, recognized experts in the fields of hydrology, hydrogeology, limnology, and other scientific disciplines relevant to the matters being reviewed. The District was directed by the Florida legislature to establish minimum flows for surface water courses and minimum levels for aquifers and surface waters. Under the statute, a minimum flow for a given surface water course is the limit at which further withdrawals would be significantly harmful to the water resource or ecology of the area. The minimum water level is the level of the ground water in an aquifer, or the level of the surface water, at which further withdrawals would be significantly harmful to the water resource of the area.

Charge

The charge for the peer review panel was to review scientific and technical data and methodologies used in the development of the proposed MFL for St. Lucie River and Estuary (SLE). In addition to copies of a number of the key supporting references used by the District, the panel was also provided with questions from the public obtained at the 8 June 2001 Rule Development Workshop, in writing and orally at the 28 June 2001 workshop, and via the web conference board that has not been initially provided by the District. All panel requests for information were met by the District in a timely manner.

Development of the proposed MFL's was a result of legal and policy interpretations of the MFL statue. The panel was asked to treat legal and policy considerations as assumptions or conditions for the technical review and therefore not within the scope of the review process. Statue requires the use of the "best available information" for calculating the MFL's.

Specifically, the panel was asked to evaluate the methods used by the District for the MFL's by completing five Tasks:

Task 1. Review Background Materials, Write Preliminary Review and Questions for Staff-

Consideration of this task required addressing both general and specific questions outlined in the Charge.

General questions:

1. Does the MFL document present a feasible scientific basis for setting initial minimum

flows and levels within the above water resource? Are the approaches or concepts described in the document scientifically sound based on "best available information"?

2. Are the proposed criteria logically supported by "best available information" presented in the main body of the document? What additions, deletions or changes are recommended by the Expert to enhance the validity of the document?

3. Are there other approaches to setting the criteria that should be considered? Is there available information that has not been considered by the authors? Is so, please identify specific alternatives to setting the MFL's and the data available to validate the alternative approach.

Specific technical questions evaluated include the appropriateness of:

- the use of the Valued Ecosystem Component (VEC) approach for establishing an MFL;
- the choice of oligohaline habitat as an MFL VEC;
- the completeness of literature review for the intended purpose;
- the freshwater flow links to biological communities (has a scientific linkage been clearly established?);
- the use and interpretation of two-dimensional hydrodynamic-salinity modeling of the effects of various freshwater flow regimes in the estuary;
- the movement and location of oligohaline habitat;
- the positive and negative effects of various freshwater flow regimes on the river and estuary; and
- the freshwater flow regime proposed during drought conditions.

Task 2. Participate in a Field Trip of the Ecosystem - District staff led a helicopter flight for a large-scale overview of the watershed and boat trip for a close-up view of the SLE ecosystem.

Task 3. Public Workshop - A public workshop was held where District staff made presentations about the preparation, development and interpretation of the MFL document. The public was also invited and when appropriate asked specific questions and made informed statements about the document and MFL plan. After all input and discussion, the review panel met in executive session and developed a detailed outline and assigned writing tasks to be eventually completed through the District's web board.

Task 4. Draft Peer Review Panel Report; Panel Findings - The draft final report is a composite of the opinions of the scientific panel based on the MFL document, knowledge gained from the field trip, discussions at the workshop and input from the public. This document was developed via the executive session and subsequent web board communications of the panel.

Task 5. Final Peer Panel Report: Assembly, Editing and Delivery to District - The panel Chairperson compiled the final peer panel report, make any necessary changes, conduct an internal panel review, get sign-off from the panelists and assemble to final product for delivery to the District via the web board.

Panel Organization

The peer review panel was composed of three academic scientists with complementary expertise: Dr. Mark S. Peterson (fish ecologist with expertise in oligohaline habitats); Dr. Ed Buskey (estuarine ecologist with expertise in hypersaline habitats) and Dr. Wu-Seng Lung, P.E. (environmental engineer with expertise in water quality modeling).

Panel Activities

The peer review panel conducted all its work according to the terms of the Florida sunshine law. All meetings and communication among panelists were at a noticed open meeting or via the District's web board, which was available for public viewing. The panel met to consider the minimum flow during the following dates:

Date (2001)	**Activity**
June 5	Review draft and materials/written response
June 27	Field trip to SLE
June 28	Public workshop and executive session
July 18	Draft final report due
July 31	Final report due (Chairperson only)

REVIEW OF MODELING STRATEGY

Salinity Data to Support Hydrodynamic Modeling

Salinity is one of the key factors in assessing the ecological impact of minimum flows in the SLE. Sudden salinity variation due to alteration in freshwater inflow can significantly affect the brackish water biota. It is essential that the dynamic changes of the location of the oligohaline zone be accurately predicted under a wide range of freshwater flow conditions in the system. Salinity data is needed to support the hydrodynamic modeling effort. No salinity data from the study area are presented in the Draft Technical Documentation to Support the Development of Minimum Flows for the St. Lucie River and Estuary (SFWMD, 2001). A review of the historical data has indicated that salinity has been routinely monitored in the SLE since 1989 under the SWIM program (Chamberlain and Hayward, 1996). Figure 1 shows the monitoring stations in the study area where salinity and nutrient data have been collected during the past decade.

Spatial distributions of salinity along the SLE are similar to those observed in many coastal plain, partially mixed estuaries. Figure 2 shows the longitudinal profile of surface salinity in the SLE under high and low inflows. Note that Stations SE00 to SE03 are in the lower estuary (see Figure 1). Stations SE05 and SE06 are in the North Fork while Stations SE08 and SE10 are in the south direction under high inflow conditions. In fact, the oligohaline zone occurs at about 5

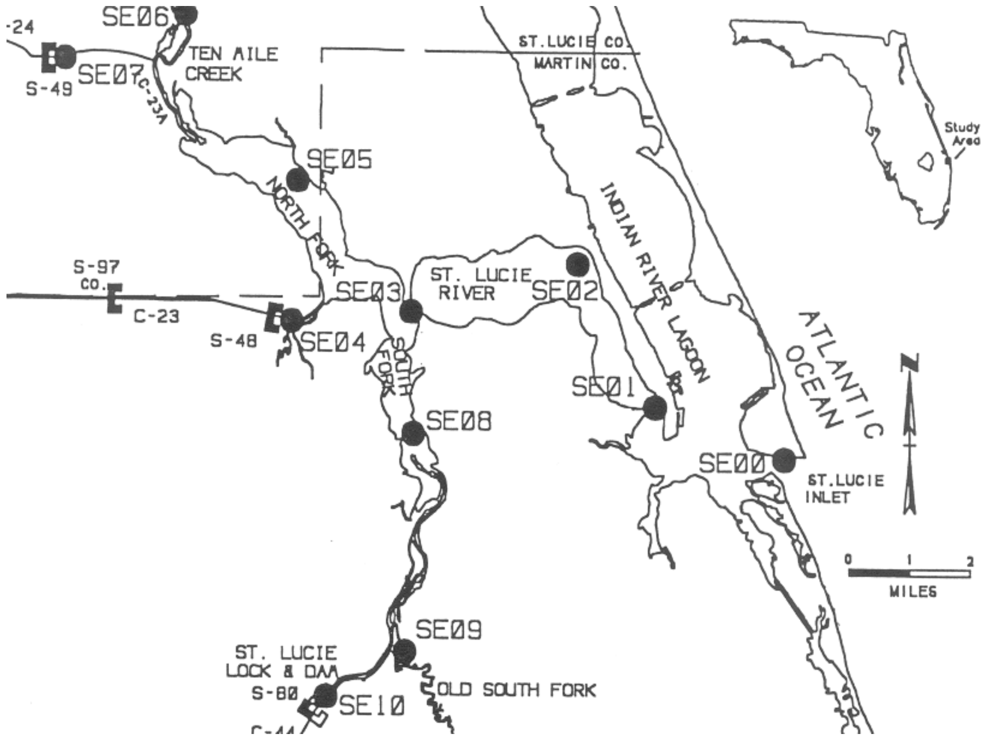


Figure 1. St. Lucie River and Estuary Sampling Stations (SE00-SE10)

miles from the mouth of the river. Under low inflows, the salinity intrusion reaches very far upstream with the oligohaline zone in the North Fork starts at about 14 miles from the mouth.

Vertical salinity gradients strongly affect the dissolved oxygen (DO) concentrations in the SLE. Fifty-one percent of the below-2 mg/L DO cases were associated with high salinity stratification values between 2 and 4 ppt/m (Chamberlain and Hayward, 1996). However, these typically occurred at the tributary heads, when temperature was high and circulation was minimal (i.e., no inflow). Although DO conditions greatly improved at the tributary heads during high-flow circulation, the remainder of the estuary experienced a DO sag caused by strong salinity stratification.

Hydrological Modeling of the Watershed

The hydrological simulations were performed using the HSPF modeling framework for the St. Lucie River Basin. Model results of stages and flows match the data well. It is recommended that statistical analyses be conducted to quantify the goodness-of-fit between the calculated and measured daily flows at the three structures: S-49, S-97, and S-80. The calculated daily flows should be used in the hydrodynamic model to drive the salinity simulations. In addition, a quantitative analysis of the model results vs. data (flow and temperature) should be performed. The latest watershed modeling effort for the Chesapeake Bay Program may be consulted for a variety of statistical analyses for the HSPF model results vs. data. The Chesapeake Bay Watershed Modeling Website is http://www.chesapeakebay.net/temporary/mdsc/index.htm.

Hydrodynamic Modeling

Appendix F of the Draft Technical Documentation presents two methods to quantify salinity distributions in the SLE: 1-D analytical solution and 2-D RMA model. Following the discussion with the District staff at the public workshop on June 28, it is clear that the 2-D RMA model is the only in-house tool currently used for the SLE. It is also understood that the model's upstream boundary will be extended further upstream to the location where the low inflow of 20 cfs is established in the North Fork of the St. Lucie River. It is recommended that additional modeling

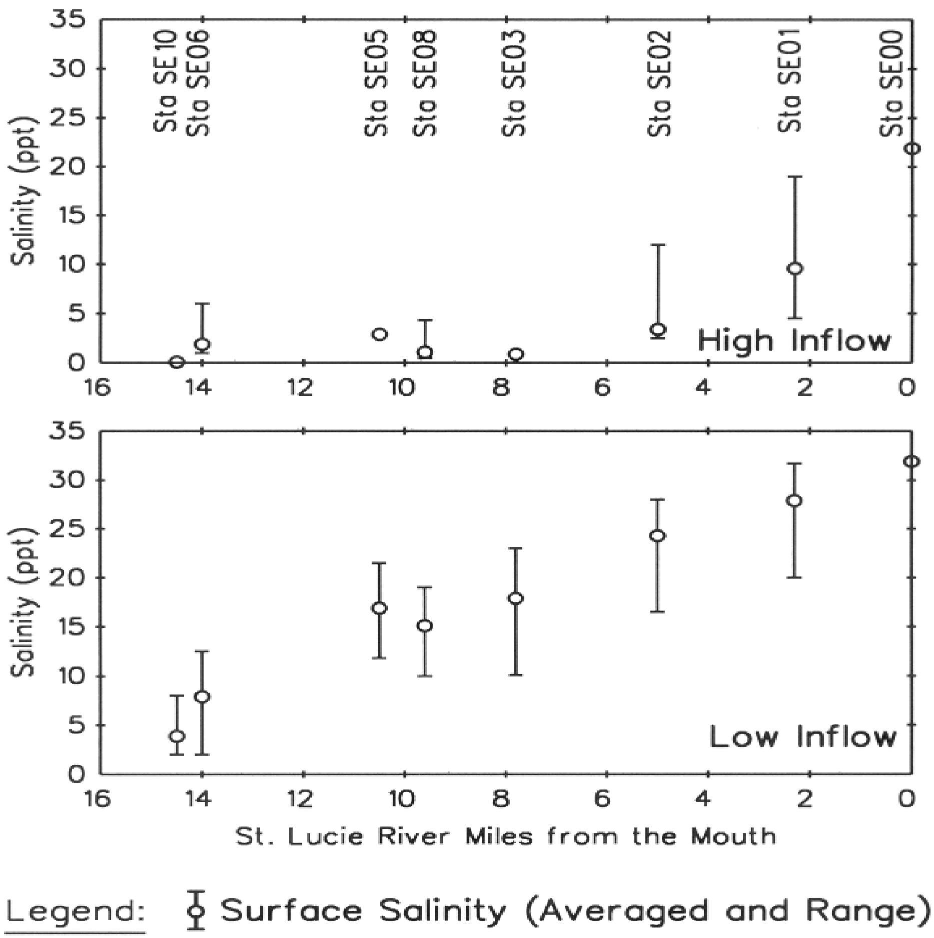


Figure 2. Salinity Data – St, Lucie River and Estuary (from Chamberlain and Hayward, 1996)

results of salinity be presented in the Final Technical Documentation to document model calibration using available salinity data. Quantitative assessment of the goodness-of-fit between the model results and salinity data must be included.

There is no mention of the linkage between the watershed model and the hydrodynamic model in the Draft Technical Documentation. An ideal simulation scenario to fully validate the hydrologic and hydrodynamic model simulations would be to perform a 10-year simulation to reproduce the long-term salinity data from 1989 to 1999. [Salinity data are available from the SWIM program for the St. Lucie River Estuary.

RESPONSE TO CHARGE

Reasonableness

The general approach of the methodologies used in the Draft Technical Document (SFWMD, 2001) was sufficiently developed, but a number of assumptions were made and not clearly outlined or defended. The District, however, did not sufficiently detail other impacts of the MFL's on the system as outlined below. These must be considered in the revision of this document.

The approach did consider and was developed based upon methods used in other areas of the country. Given the deficiencies outlined in this report, the expert panel believed the document taken in total is a well-developed start at dealing with the MFL issue for SLE. Generally, a management objective was stated and the estimated response can be judged successful within an acceptable range of error. The expert panel, however, has provided some additional metrics and approaches that should be considered in their Final Technical Document.

Editorial Comments

The expert panel has pointed out some needed editing of the Technical Document in our initial written responses. Additionally, there is some cited literature (Cox *et al.*, 1994; Kemp *et al.*, 1983; Twilley *et al.*, 1985; Cooper and Ortel, 1988; Sculley, 1996; a large number in Table 4-1and and probably other Tables as well) that does not appear in the Literature Cited section. Additionally, there are a number of fish and shellfish names (both scientific and common names) that are not correct in Table 4-1 (*sensu* Robins *et al*. 1991; Perez Farfante and Kensley 1997). These need to be corrected in the Final Technical Document.

Table name	**Correct name**
Striped moharra	Striped mojarra
Moharra	Mojarra
Mosquito fish	Mosquitofish
Gombiosoma bosci	*Gobiosoma bosc*
Micropogon undulates	*Micropogonias undulates*
Panaeus aztecus	*Farfantepenaeus aztecus*

External Comments on MFL

During the public meeting a representative of the River Initiative presented the groups concerns about the Technical Document. They are concerned that 1) the spirit of the document of setting the MFL as a "starting point" may not survive imminent rule development and eventual legal wording, 2) that setting the MFL so low may lead to greater use-permitting, and 3) that the MFL's based on the natural systems model during dry times is actually lower than the long-held belief of larger flows during dry times than observed today. In general, the River Initiative feels the 21 May 2001 document as written is a good starting point. All of the above concerns appear an issue of "policy" and are not in the purview of the expert panel (SFWMD, 2001). These should be addressed by the District in the Final Technical Document prior to setting the final MFL's.

Written public comments and questions obtained at the 8 June 2001 Rule Development Workshop were provided to the expert panel during the site visit. The concerns were 1) use of the word "oligohaline" instead of oligosaline; 2) targeting only the SLE in St. Lucie County with little discussion of the SLE in Martin County; 3) quality of the fresh water entering the SLE, and 4) the perceived omission of a serious discussion concerning the Upper east Coast regional Water Supply Plan's indication that 84% of the fresh water in the planning area is being used for agriculture, leaving only 16% for consideration.

Item #4 above appears to be a "policy" issue whereas the other three items can be addressed in this report. The term "oligohaline" is the correct term and is grounded in estuarine science. Clearly there are more data available from the St. Lucie County portion of the SLE (North Fork) than the Martin County portion (South Fork). The data and simulations for South Fork should be considered preliminary in nature. Finally, the water quality issues raised are also a concern of the expert panel and should be addressed in the Final Technical Document as indicated below.

Deficiencies

Minimum flow recommendations for the SLE are set based on flows that would cause harm or significant harm to the predefined VEC. The draft report sets the VEC for the SLE as the establishment of an oligohaline zone (salinities of 0.5 to 5 ppt salinity), with the implicit assumption that establishment of this zone will protect and encourage development of biota that comprise a loosely defined set of VEC's. The most serious deficiencies in this plan are the lack of direct evidence connecting the oligohaline zone to tangible evidence of enhancement of VEC's and the lack of consideration of other potential benefits, such as nutrients and organic matter, that are associated with the freshwater inflows to the estuary and may be required to maintain estuarine productivity. These deficiencies are not associated with any flaws in the proposed minimum flow criteria, but are simply due to a lack of information on this particular estuarine system. These can be corrected with appropriate research projects, and an adaptive management strategy is strongly recommended by the expert panel such that minimum flow requirements could be altered if necessary.

Connection of Oligohaline Zone to VEC's

There has been relatively little direct study of value, productivity and species associated with oligohaline environments. However, it is clear that insufficient freshwater inflow can have important negative impacts on estuarine systems (e.g. Holmquist *et al*., 1998). In the documentation provided to the expert panel, emphasis seemed to be placed on the potential for using submerged aquatic vegetation (SAV) or oyster reefs as VEC (see St. Lucie Estuary Historical, SAV, and American Oyster literature review). These VEC have been used in other estuaries, and both components not only have value themselves for primary and secondary production of estuaries, but also provide important habitats for a wider range of organisms. However, our tour of the SLE revealed that shallow benthic habitat appropriate for SAV or oyster beds is very limited in the North Fork of the SLE, which has steep banks after being dredged to aid in flood control. It was clear after discussion with District personnel, that productivity in the SLE is thought to be primarily from phytoplankton, so although enhancement of SAV and oysters may be a good restoration goal, these components may have limited value as VEC is the SLE in terms of setting MFL's.

There has been less study of the importance of oligohaline zones to plankton based estuarine communities. Laboratory studies clearly indicate that most estuarine and marine phytoplankton have clear salinity preferences, with maximum growth rates occurring over specific salinity ranges, and species diversity declining under both oligohaline and hypersaline conditions (Brand, 1994; Buskey *et al*., 1998). There is no clear evidence that shows oligohaline zones provide for enhanced quality or quantity of phytoplankton production. There are highly productive species of zooplankton that appear capable of inhabiting the oligohaline zones of estuaries (e.g. species of the genus *Acartia* and *Eurytemora*) in subtropical environments, although high flows of freshwater into estuaries tend to physically displace estuarine zooplankton and replace them with freshwater zooplankton community, although when salinities increase the estuarine species return (Gillespie, 1971; Matthews, 1980; Kalke, 1981). However, oligohaline salinities are not favored by these species, and their biomass and productivity maxima are not associated with these salinity ranges (Heinle, 1966; Farmer, 1980; Roddie *et al*., 1984).

Planktonic organisms tend to be physically displaced along with oligohaline and mesohaline waters during high flow events, so they are rarely exposed to rapid changes in salinity. This is not true for benthic plants and animals such as SAV and oysters that remain in place as salinities of their surrounding waters change. The minimum flow criteria for the SLE aims to establish an oligohaline zone as a VEC, but the location of this oligohaline zone is flexible, and will move up and down the estuary as flows increase above the minimum. The range of salinity tolerances and the effects of rate of change of salinity on fixed benthic VEC such as SAV and oyster beds needs to be considered.

Tidal-River Nekton

There is, however, considerable descriptive data on the importance of oligohaline habitat to both freshwater and estuarine-dependent nekton during all or part of their life history. The nekton distributions in the SLE are important because they define freshwater and oligohaline assemblages that can be influenced by the minimum flow rule. Tidal rivers are defined as water bodies that receive freshwater from areas other than runoff (from the upstream watershed), are flushed to some extent during a tidal cycle and are subject to salt intrusion from downstream areas (Hackney *et al*., 1976). These important tributaries are part of the estuarine landscape that is known for its biodiversity and productivity worldwide (Gunter, 1967; Szedlmayer, 1991; Peterson and Ross, 1991; Wagner and Austin, 1999).

Many estuarine-dependent fishes and crustaceans like snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellatus*), and pink shrimp (*Farfantepenaeus duorarum*), for example, utilize all or a portion of tidal rivers as nursery habitat. These estuarine-dependent transients, tidal river residents like members of the families Atherinidae (silversides), Cyprinodontidae (killifishes) and Poecillidae (livebearers), and secondary freshwater species like sunfish and black basses (Centrarchidae), and catfishes (Ictaluridae) comprise the fish fauna of low salinity tidal rivers. There is a strong relationship between salinity and size in a great number of estuarine-dependent transient fishes and crustaceans in estuaries and coastal ecosystems (Sykes and Finucane, 1966; Rogers *et al*., 1984; Szedlmayer, 1991; Peebles and Flannery, 1992; Wagner and Austin, 1999), indicating that young developmental stages of organisms are found abundantly in low salinity habitats.

Seasonal variation in a number of abiotic parameters is a common pattern in estuarine systems. In fact, recruitment events of many estuarine organisms are timed to take advantage of this variability. For example, Sykes and Finucane (1966) determined that Tampa Bay species of commercial importance varied seasonally and spatially within the bay, which corresponded to seasonal salinity variation. Hughes (1969) determined that postlarval pink shrimp (*F. duorarum*) could perceive and respond to salinity changes as small as 1 ppt. He found postlarvae were more active in high salinity and that in low salinity they dropped to the substratum whereas juveniles were positively rheotactic when Anormal@ seawater salinities were encountered, thus swimming against the current. When salinities were lower (ebb tide), juvenile pink shrimp swam downstream with the current. This mechanism facilitated offshore movement of the larger pink shrimp. These data illustrate the need to maintain normal freshwater flows from tributaries to bays for recruitment of this commercially important crustacea. Perez (1969) also determined that juvenile spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogonias undulatus*) both responded to gradual rates of salinity change by increased swimming compared to fixed or severely fluctuating salinity conditions, allowing young fishes to move into areas in the estuary where salinity fluctuation was gradual or constant compared to severely fluctuating. Rogers *et al*. (1984) determined that individuals of several seasonal recruiting species (Atlantic flounder, *Paralichthyes lethostigma*, Atlantic menhaden, *Brevoortia tyrannus*, silver perch, *Bairdiella chrysoura*, and spot) appear to move preferentially to primary nursery zones at the most inland locations in Georgia, subsequently moving to deeper or more saline waters as they grow. Recruitment was timed to spring freshwater flows into the marsh. In the Tampa Bay area, Peebles and Davis (1989) determined that peak spawning activity occurs between March and August in the Little Manatee River with early juvenile estuarine-dependent species (*C. undecimalis*, spotted seatrout, *Cynoscion nebulosus*, and *S. ocellatus*) concentrated in low salinity areas (> 75 % abundance in < 18 ppt. Finally, Longley (1994) determined that estuaries are by definition dynamic and water management activities should attempt to parallel those dynamic patterns of freshwater inflow A...within the productive range, both seasonally and annually...@. AThe seasonal timing of freshwater inflows is most important because adequate inflows during critical periods of reproduction and growth can produce greater benefits than constant inflows throughout the year@.

Water Quality Impacts of MFL's

One of the serious deficiencies in the Draft Technical Documentation is the lack of discussion on the water quality impact. It should be pointed out that several water segments in the St. Lucie River Basin are listed in the 303(d) list for water quality impairment: St. Lucie Estuary, St. Lucie Canal, and South Fork St. Lucie River. In light of the statement by Chamberlain and Hayward (1996) that more stable, lower flows will improve water quality in the SLE, it is important to quantify the water quality impact of lower inflows. While it is logical to approach MFL's from a point of view of maintaining habitats within certain salinity ranges, and since freshwater inflow to estuaries also brings with it more that fresh water (e.g. nutrients, dissolved and particulate organic matter, inorganic particles including silts, clays, sand), the effects of altering these inputs should also be considered.

A water quality model is an appropriate tool to perform such an analysis. In particular, the water quality model can be designed to address the following questions related to MFLs:

1. What are the nutrient loads under the minimum flows?
2. How does the SLE respond, in terms of algal growth and dissolved oxygen, to a prolonged period of minimum flows?
3. Under low inflow conditions, the salinity levels become well mixed in the water column, yet further salinity intrusion will take place. On the other hand, the water column becomes more stratified under high inflows. Would this intensify the dissolved oxygen stratification in the water column?
4. What is the role of sediments in contributing to benthic oxygen demand and nutrient fluxes when the bottom layer of the water in the estuary becomes anaerobic?

Perhaps modeling studies in the St. Lucie Estuary TMDL effort should be consulted for the SLE MFLs. Although the St. Lucie Estuary TMDL is to be completed, it is recommended that their results should be incorporated into the SLE MFLs in the future.

Nutrients

Freshwater inflow to the SLE may provide an important source of inorganic nutrients that support the primary productivity of this system. While excess nutrient may be a concern in terms of eutrophication and potential for hypoxic or anoxic environments associated with organic loading, the SLE also depends on a minimum input of new nutrients to this system to maintain productivity (Nixon, 1981). It seems unlikely that short-term limitation of new nutrients to the SLE would lead to a reduction in productivity that would be harmful to the system, but the role of this input of new nutrients should be considered in determining MFL's. The timing of freshwater inflows can also impact the nature of the phytoplankton community in an estuary.

There is good experimental and theoretical evidence that a pulsed freshwater release will ultimately result in greater production of fish and larger consumers compared to when water is allowed to "trickle" into the system. larger planktonic primary producers are able to sequester a greater proportion of growth-limiting nutrients when they are presented at elevated concentrations over a short time interval (Suttle *et al.,* 1988), therefore a pulsed nutrient supply will select for larger phytoplankton (Turpin and Harrison, 1980; Suttle *et al.,* 1987). This results in a food-web based on large-size phytoplankton, which is more efficient in transferring nutrients and energy to higher trophic levels than is a food-web based on pico- or nanoplankton (Suttle *et al.,* 1990).

DOC and POC

Input of dissolved (DOC) and particulate organic carbon (POC) to estuaries can come from terrestrial or riverine sources, as well as from primary and secondary production within the estuary. Terrestrial inputs of DOC and POC to the SLE will be impacted by minimum flow requirements. At this point there is no information available as to the relative importance of this imported carbon to the productivity of the SLE, but it should also be considered when setting minimum flows. Relative importance of phytoplankton, seagrasses and terrestrial carbon can be estimated by examining the stable carbon isotope ratios of POC and various marine organisms (e.g. Fry and Sherr, 1984). Reduced import of organic matter could also in turn affect rates of benthic nutrient flux and biological oxygen demand of sediments.

Inorganic Particles and Sediment Quality

Another factor to consider may be the impact of reduced flow on accumulation of low-quality muck sediments. By reducing imported organic matter and nutrients, organic loading of muck type sediments in the SLE may be reduced, and frequency of hypoxic and anoxic events might be reduced. Alternately, reduced flow might also encourage the accumulation of muck sediments in areas where they would be scoured and carried down stream during periods of higher flow.

CONCLUSIONS AND RECOMMENDATIONS

The expert panel thinks the Draft Technical Document (SFWMD, 2001) is an appropriate “conceptual” approach to the issue of establishing MFL’s but it lacks in important data sets and makes a number of unstated or poorly understood assumptions (e.g., connection of oligohaline and VEC’s, water quality impacts, importance of water flow to the estuary in additions to its role in salinity, etc.). These are outlined in detail above and should be considered by the District when developing the Final Technical Document.

The process of adaptive management requires a clear management goal (such as, maintaining a certain area or volume of oligohaline habitat during certain seasons), monitoring (which can be restricted to the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and re-evaluation of the MFL's on short-term intervals. Without knowing how much (or when) oligohaline habitat is required to maintain or enhance productivity in the SLE, there is no clear, compelling minimum flow rate. Therefore, setting the management goal will require evaluation of the biological communities and environmental setting, and policy decisions on which natural resources are to be conserved, protected, or optimized. Monitoring could be economical because the main variables of interest (salinity and DO) are inexpensive to measure and are automated This focused monitoring activity would allow for annual evaluation and refining of the MFL's

Terminology

The expert panel suggests that a listing of terms, definitions and abbreviations be incorporated into the revised technical document. In particular, the expert panel would like to see more clear definitions of harm, significant harm and serious harm if possible. We noted some differences in the Draft Technical Document and how staff used these terms during our site visit. The expert panel noted that is some places in the document the definition of significant harm referred to "seasons" whereas in other places it refers to "years." Clearing these issues up will make it easier for the non-expert to understand and appreciate the Final Technical Document.

Future Monitoring

-compare the rates of primary productivty and phytoplankton biomass of the oligohaline and mesohaline zones of the SLE.

-compare zooplankton biomass in oligohaline and mesohaline zones of the SLE.

-investigate tolerances of sedentary benthic plants and animals (SAV and oysters) to rapid changes in salinity.

-determine relationship between freshwater inflow and nutrient loading of SLE.

-determine the original sources of carbon used by VEC of SLE using stable carbon isotope analsysis or biomarker methods.

-evaluate the impacts of MFL's on sediment accumulation in SLE.

LITERATURE CITED

Brand, L.E. 1984. The salinity tolerance of forty-six marine phytoplankton species. *Estuarine, Coastal and Shelf Science* 18:543-556.

Buskey, E. J., B. Wysor and C. Hyatt 1998. The role of hypersalinity in the persistence of the Texas "brown tide" bloom in the Laguna Madre. *Journal of Plankton Research* 20:1553-1565.

Chamberlain, R. and Hayward, D. 1996. Evaluation of water quality and monitoring in the St. Lucie Estuary, Florida. *Water Resources Bulletin* 32:681-696.

Doering, P.H. 1996. Temporal variability of water quality in the St. Lucie Estuary, South Florida. *Water Resources Bulletin* 32:1293-1306.

Farmer, L. 1980. Evidence for hyporegulation in the calanoid copepod, *Acartia tonsa*. *Comparative Biochemistry and Physiology* 65A:359-362.

Fry, B. and E. Sherr. 1984. Stable carbon isotope measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contributions in Marine Science* 27:13-47.

Gillespie, M.C. 1971. Analysis and treatment of zooplankton of estuarine waters of Louisiana. Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana Phase IV. Biology. Louisiana Wildlife and Fisheries Commission, pp. 108-175.

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. *In*: *Etuaries* (Publication No. 83) (Ed: Lauff, G.H.), American Association for the Advancement of Science, Washington, D.C., pp. 621-638.

Hackney, C.T., W.D. Burbanck and O.P. Hackney. 1976. Biological and physical dynamics of a Georgia tidal creek. *Chesapeake Science* 17:271-280.

Heinle, D.R. 1966. Production of a calanoid copepod, *Acartia tonsa*, in the Patuxent Estuary. *Chesapeake Science* 7:59-74.

Holmquist, J.G., J.M. Schmidt-Gengenbach and B.B. Yoshioka. 1998. High dams and marine-freshwater linkages: effects on native and introduced fauna in the Caribbean. *Conservation Biology* 12:621-630.

Hughes, D.A. 1969. Responses to salinity change as a tidal transport mechanism of pink shrimp, *Penaeus duorarum*. *Biological Bulletin* 136:43-53.

Kalke, R.D. 1981. The effects of freshwater inflow on salinity and zooplankton populations at four stations in the Nueces-Corpus Christi and Copano-Aransas Bay systems, Texas from October 1971 - May 1975. pg. 454-471. *In*: R.Cross and D. Williams (eds) Proceedings of the

National Symposium on Freshwater Flow to Estuaries, US Fish and Wildlife Service, Office Biological Service, Publication #FWS10BS-81/04.

Longley, W.L. (Ed). 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386p.

Matthews, G.A. 1980. A study of the zooplankton assemblage of San Antonio Bay, Texas and the effects of river inflow on the composition and the persistence of this assemblage. PhD dissertation , Texas A&M University, College Station. 313 pp.

Nixon, S.W. 1981. Freshwater inputs and estuarine productivity. *In*: R.D. Cross and D.L. Williams (eds), Proceedings of the National Symposium on Freshwater Inflow to Estuaries. U.S. Fish and Wildlife Service, FWS/OBS-81/04. Washington D.C., Vol. 1, pp. 31-57.

Peebles, E.B. and S.E. Davis. 1989. Riverine discharge and estuarine fish nurseries: first annual report for the ichthyoplankton survey of the Little Manatee River, Florida. SWFWMD, Brooksville, FL.

Perez, K.T. 1969. An orthokinetic response to rates of salinity change in two estuarine fishes. *Ecology* 50:454-457.

Perez Farfante, I. and B. Kensley. 1997. Penaeoid and sergestoid shrimps and prawns of the world. Keys and diagnoses for the families and genera. Memoires du Museum National D'Histoire Naturalle, Tome 185 Zoologie, Editions du Museum, Paris. 233p.

Peterson, M.S. and S.T. Ross. 1991. Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. *Estuarine, Coastal and Shelf Science* 33:467-483.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. A list of common and scientific names of fishes from the United States and Canada. 4th edition, American Fisheries Society, Special Publication No. 12. 174p.

Roddie, B.D., R.J.G. Leaky and A.J. Berry. 1984. Salinity-temperature tolerance and osmoregulation in *Eurytemora affinis* (Poppe) (Copepoda: Calanoida) in relation to its distribution in the zooplankton of the upper reaches of the Firth Estuary. *Journal of Experimental Marine Biology and Ecology* 79:191-211.

Rogers, S.G., T.E. Targett and S.B. Van Sant. 1984. Fish-nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Transactions of the American Fisheries Society* 113:595-606.

South Florida Water Management District (2001). Draft Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary. Water Supply Division, SFWMD, West Palm Beach, Florida. 80p.

Suttle, C.A., J.A. Fuhrman and D.G. Capone. 1990. Rapid ammonium cycling and concentration-dependent partitioning of ammonium and phosphate: implications for carbon transfer in planktonic communities. *Limnology and Oceanography* 35:424-433.

Suttle, C.A., J.G. Stockner and P.J. Harrison. 1987. Effects of nutrient pulses on community structure and cell size of a freshwater phytoplankton assemblage in culture. *Canadian Journal of Fisheries and Aquatic Sciences* 44:1768-1774.

Suttle, C.A., J.G. Stockner, K.S. Shortreed and P.J. Harrison. 1988. Time-course of size-fractionated phosphate uptake: are larger cells better competitors for pulses of phosphate than smaller cells? *Oecologia* 74:571-576.

Szedlmayer, S. 1991. Distribution and abundance of nearshore fishes in the Anclote River estuary, west-central Florida. *Northeast Gulf Science* 12:75-82.

Sykes, J.E. and J.H. Finucane. 1966. Occurrence in Tampa Bay, Florida, of immature species dominant in Gulf of Mexico commercial fisheries. *Fishery Bulletin, U.S.* 65:369-379.

Turpin, D.H. and P.J. Harrison. 1980. Cell size manipulation in natural marine planktonic diatom communities. *Canadian Journal of Fisheries Aquatic Sciences* 37:1193-1195.

Wagner, C.M and H.M. Austin. 1999. Correspondence between environmental gradients and summer littoral fish assemblages in low salinity reaches of the Chesapeake Bay, USA. *Marine Ecology Progress Series* 177:197-212.

SFWMD RESPONSE TO THE SCIENTIFIC PEER REVIEW PANEL DRAFT REPORT

South Florida Water Management District (SFWMD or District) staff have reviewed the document entitled, *First Draft Final Report,* dated July 10, 2001, that was prepared by the scientific peer review panel to support development of minimum flows and levels (MFLs) for the St. Lucie River and Estuary. The panel spent a good deal of time and effort to review the materials provided, absorb the information presented, and compile this document in a short period of time. The analysis, comments, and suggestions provided will greatly improve our final work product. District staff particularly appreciate that the panel's comments were constructive, in the sense that issues or concerns were clearly identified and stated, and that constructive solutions or approaches to deal with these issues were also provided.

We agree in concept with most of the information and conclusions provided in the draft report. In several cases, we feel that the panel failed to adequately recognize or consider work that the District has done to address some of the issues raised. In retrospect, in most cases, the failure was not due to the panel's understanding, but rather to deficiencies in the report and supplemental information. Many of these issues have been addressed in this draft of the report. Additional information and better explanations of the issues raised by the panel have been provided.

This draft of the *Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary* report includes both a copy of the panel's report and District staff responses to the specific comments and questions raised in the peer review report, including a description of how these issues were addressed in the revised technical document. A list of **Acronyms and Abbreviations** and a **Glossary** were added to ensure standardized terminology. Also, an **Executive Summary** targeted for lay readers and nonscientists has also been added.

In general, the panel focused on three major areas where additional information was needed. These were salinity modeling, water quality, and developing a better linkage between the oligohaline zone and enhancement of valued ecosystem components (VECs) in the St. Lucie River and Estuary. While, staff has included some additional information and clarified some of these issues, additional efforts will be needed to further analyze historical data sets and collect new data to provide adequate treatment of these concerns. Such efforts were not feasible within the time frame of the current MFL development process and will need to be provided in future updates.

One especially important point is that the report needs to emphasize the "adaptive management approach" to developing and implementing these MFLs. While District staff implicitly understood that the adaptive approach was the basis for our proposed management strategy, we failed to use that terminology in the report.

Panel chairman Dr. Mark Peterson noted that "none of the District's comments required modification of the final document." Therefore, the scientific peer review panel's final report remained unchanged from the *First Draft Final Report*. Specific issues and recommendations included in the panel's final report relating to the development and documentation of technical criteria are itemized below. Responses to panel concerns are addressed either in this appendix or within the body of the revised document. In the latter case, reference will be made to the appropriate section.

Issues

- Model linkage not adequately explained
- Lack of direct evidence connecting oligohaline zone to tangible VEC enhancement
- Lack of discussion on water quality impact
- Clarification of the terms harm, significant harm, and serious harm
- Minor editorial corrections

Recommendations

- Additional salinity modeling results need to be presented to document model calibration using available salinity data
- Implement adaptive management strategy to further develop minimum flow requirements
- Develop water quality model to address MFL related questions
- Establish a research plan to fill critical information gaps. Future investigations should do the following:
  - Compare primary productivity and phytoplankton biomass of the St. Lucie Estuary oligohaline and mesohaline zones
  - Compare zooplankton biomass in the St. Lucie Estuary oligohaline and mesohaline zones
  - Investigate tolerances of sedentary benthic plants and animals (submerged aquatic vegetation and oysters) to rapid changes in salinity
  - Determine the relationship between freshwater inflow and nutrient loading
  - Determine the original sources of carbon used by VECs of the St. Lucie Estuary using stable carbon isotope analysis and biomarker methods
  - Evaluate the impacts of MFLs on sediment accumulation in the St. Lucie Estuary

Response to Issues

Model Linkage Not Adequately Explained

Chapter Four's section on **Hydrologic and Hydrodynamic Modeling** was revised to improve descriptions of, and interactions among, models used in the hydrologic evaluation of the St. Lucie River and Estuary watershed.

Lack of Direct Evidence Connecting Oligohaline Zone to Tangible VEC Enhancement

The loss of low salinity habitat (oligohaline zone) in the St. Lucie Estuary was chosen as an indicator of significant harm for the estuary. One of the major justifications for using this habitat as a VEC was its importance to the life history of many fish species. A list of species from the literature that may be affected by the loss of this habitat was provided. The review panel indicated that additional information regarding endemic species was needed from available literature in order to provide the evidence needed for connecting oligohaline zone protection to tangible VEC enhancement. The list in Chapter 4 (**Table 9**) was expanded to include species collected in low salinities during the dry season in the St. Lucie Estuary. An additional discussion of VEC species and relationships to oligohaline habitat entitled **Proposed Valued Ecosystem Component for the St. Lucie Estuary** was included in Chapter 4.

Lack of Discussion on Water Quality Impact

Water quality impacts are more appropriately addressed in the *Indian River Lagoon Surface Water Improvement and Management (SWIM) Plan* (Steward et al., 1994), which is currently being updated. However, understanding that water quality is an area of critical concern to the river and estuary, this document has been revised to include a more detailed discussion of water quality issues and monitoring efforts in Chapters 2, 3, and 4 (**pages 26**, **47**, and **69**, respectively), including discussions regarding the effects of minimum flows on water quality.

Clarification of Terms

The legal definition of harm, significant harm, and serious harm is provided in the **Level of Protection for Water Resource Functions Provided by the MFL Standard of Significant Harm** section in Chapter 1. Minimum flows and levels relate to the significant harm standard. This standard is defined in terms of the duration of the recovery period, which is the "temporary loss of water resource functions... that takes more than two years to recover." The relationship of minimum flows to significant harm in the St. Lucie Estuary is defined in the **Proposed Criteria** section in Chapter 6. It is assumed in this definition that the duration of the recovery period is measured from the point at which harm first occurs.

Response to Panel Recommendations

Additional Salinity Modeling Results Should Be Presented to Document Model Calibration Using Available Salinity Data

The recalibration effort continues as new data sets become available. Florida Department of Environmental Protection (FDEP) data was used in the current recalibration simulation, results of which are expected to be available in November 2001. The following is a summary of this effort to date.

On page 3 of review panel's final report, it was recommended that, ". . . additional modeling results of salinity [should] be presented in the Final Technical Documentation to document model calibration using available salinity data. Quantitative assessment of the goodness-of-fit between the model results and salinity data must be included." Based on this recommendations, further calibration of the hydrodynamic and salinity model has been undertaken. The calibration data set covered a 2.5-month period from September 1999 to December 1999. Water level was measured every 15 minutes at the St. Lucie Inlet by FDEP. Salinity and water level were measured at the A1A, Roosevelt, and Kellstadt Bridges. Velocity was also measured at the Kellstadt Bridge. Inlet water level data were compared to 1998 calibration data and data from the National Ocean and Atmosphere Administration tide books to determine necessary corrections. These corrected data were then used as boundary conditions for the model. Lake of velocity measurement data at A1A and Roosevelt Bridge restricted the calibration at these two stations.

Lack of bathymetry data and inadequate flow data on the North Fork of the St. Lucie River further restricts calibration. Currently, discharge to the North Fork is estimated from Gordy Road Structure flow and the ratio between the two drainage basin areas. Calibration of velocity and salinity will continue. Further efforts will explore the available data to reach this goal.

Long-Term Simulation

On page 9 (second paragraph) of the review panel's final report the following recommendation is made: "An ideal simulation scenario to fully validate the hydrologic and hydrodynamic model simulations would be to perform a 10-year simulation to reproduce the long-term salinity data from 1989 to 1999. Salinity data are available from the SWIM program for the St. Lucie River Estuary."

The SWIM data collection program was designed for monitoring purposes. A measurement was made each month to detect the general level of salinity in the estuary. The data does not contain any time series data and does not describe the salinity variations over tidal cycles. Also, that data set does not have concurrent tidal data. While the SWIM water quality monitoring is an excellent and productive program, the salinity measurements were not intended for a hydrodynamic/salinity model validation.

In order to obtain concurrent time series data for model development, the SFWMD established a network of continuous recording stations in the St. Lucie Estuary in 1997.

The stations recorded concurrent tide/salinity/temperature data at 15 minutes intervals. The data collected in the period from November 1997 to June 1998 was used for the preliminary calibration of the St. Lucie Estuary RMA Hydrodynamics/Salinity Model.

A difficulty we had during the model development was that we did not have flow records for the South and North Forks and Basins 4, 5, and 6. In the November 1997 to June 1998 simulation, we had to use the estimated runoff for those watersheds. The runoff was provided by Lead Engineer Steve Lin using the Hydrologic Simulation Program-FORTRAN (HSPF). We intend to extend the watershed model simulation to the period from June 1998 to the end of 2000 so that we can extend the hydrodynamic/salinity model verification to the same length.

Implement an Adaptive Management Strategy to Further Develop Minimum Flow Requirements

Although an adaptive management approach including setting targets, monitoring, analysis, and reevaluation was implied in the draft technical document, it was not expressly stated as such. Appropriate sections have been revised to more clearly define the adaptive management strategy approach in the development of the St. Lucie River and Estuary MFLs.

Develop Water Quality Model to Address MFL Related Questions

The District has a water quality modeling program in place for the St. Lucie Estuary. It is primarily designed to support issues raised in the SWIM program, including the development of pollution load reduction goals (PLRGs) and total maximum daily loads (TMDLs) for the river and estuary. A brief description of this modeling effort is included in the **Research Strategy** section of Chapter 6. This model can also be applied to address issues raised by the peer review panel. For example, it can be applied to ensure that the minimum flows provided to the St. Lucie Estuary provide sufficient nutrients to maintain aquatic productivity in the estuary and the adjacent Indian River Lagoon.

Establish a Research Plan to Fill Critical Information Gaps

The St. Lucie MFL provides for an oligohaline zone in the North Fork of the estuary. The use of the oligohaline zone as the VEC upon which to base the MFL depends on the following assumptions:

- First, oligohaline zones of estuaries provide critical nursery habitat for important estuarine dependent species.
- Second, an oligohaline zone in the North Fork is beneficial to the estuary.

The first assumption is general and based on widely accepted concepts supported by the peer reviewed scientific literature. The second assumption is site specific and not well supported by site specific information. The peer review report states, "Without knowing how much (or when) oligohaline habitat is required to maintain or enhance productivity in the St. Lucie Estuary, there is no clear, compelling minimum flow rate. “The peer review report recommends that a monitoring program be instituted to evaluate the connection of the oligohaline zone and the VECs, water quality impacts, and the importance of freshwater flow to the estuary in addition to its role of controlling salinity. A number of specific projects were suggested:

- Compare primary productivity and phytoplankton biomass of the oligohaline and mesohaline zones of the St. Lucie Estuary
- Compare zooplankton biomass in the oligohaline and mesohaline zones of the St. Lucie Estuary
- Investigate tolerances of sedentary benthic plants and animals (submerged aquatic vegetation and oysters) to rapid changes in salinity
- Determine the relationship between freshwater inflow and nutrient loading of the St. Lucie Estuary
- Determine the original sources of carbon used by the VECs of the St. Lucie Estuary using stable carbon isotope analysis and biomarker methods
- Evaluate the impacts of MFLs on sediment accumulation in the St. Lucie Estuary

Both ongoing research, conducted by the District, and that planned for the future, incorporate many of the aspects of the specific projects listed above and the general areas of deficiency identified by the panel. Chapter 6 has been revised to include research priorities for continued MFL development.

Appendix J
COMMENTS RECEIVED ON THE FIRST PUBLIC DRAFT OF THE ST. LUCIE MINIMUM FLOWS AND LEVELS DRAFT TECHNICAL DOCUMENT

TABLE OF CONTENTS

ST LUCIE RIVER MFLs
RULE DEVELOPMENT WORKHSOP
JUNE 8, 2001

PUBLIC COMMENTS AND QUESTIONS

1. Why are we using the word "Oligohaline" in the document instead of Oligosaline? Oligosaline is easier to understand and reflects the intent of the protected zone of the river.

2. The areas of the river that have been targeted as "good" Oligohaline sites are all in St. Lucie County. What about areas of the river in Martin County?

3. The Upper East Coast Regional Water Supply Plan (2000), states that Agricultural water demand accounts for 84% of the overall water demand in the planning area and is expected to increase by approximately 23 percent through the planning horizon. No where can I find that this 84% of the fresh water in the Upper East Coast Area is factored into any planning. It looks to me that all other plans and projects, including the MFLs are dealing with the other 16%. It seems to be an almost fatal flaw in any planning to completely disregard 84% of the users of fresh water.

4. There is no serious discussion of the quality of fresh water. About all of the water in the Upper East Coast, probably the whole district is badly polluted by agriculture and development. The peer panel needs to give an in-depth review of the quality of water.

LLOYD BRUMFIELD
11225 SW Meadowlark Circle
Stuart, Florida 34997-2730

561-286-3244 Phone/Fax
E Mail: lloydb4@yahoo.com

June 11, 2001

Peer Review Panel
Minimum Flows and Levels for the
St Lucie River & Estuary
C/O Joel VanArman
Water Supply and Development Dept.
South Florida Water Management District
PO Box 24680
West Palm Beach, FL 33416-4680

SUBJECT: Comments on Draft, May 22, 2001--Received at Stuart City Hall---SFWMD Public Hearing June 8, 2001

My comments take the form of general observations of the SFWMD's policies, procedures and practices of dealing with water supply and quality in the Upper East Coast--Martin, St. Lucie, and a portion of Okeechobee Counties.

I. The SFWMD "Upper East Coast Water Supply Plan--Planning Document-1990-2020--January 1998."

Page 1--Chapter 1-Introduction---"Agricultural water demand, which accounts for 84 percent of the overall water demand in the planning area, is expected to increase by approximately 23 percent through the planning horizon."

No where can I find that this 84% of the fresh water in the Upper East Coast Area is factored into any planning. It looks to me that all other plans and projects, including the St. Lucie Minimum Flows and Levels, are dealing with the other 16%.

It seems to be an almost fatal flaw in any planning to completely disregard 84% of the users of fresh water.

II. Quality of Water

In my dozens, probably hundreds, of meetings, workshops, Governing Board Meetings, etc. have I heard any serious discussion of the quality of the fresh water: at most a glancing remark and get on with it. About all of the water in the Upper East Coast, probably the whole district, is badly polluted mainly by agriculture and development.

The Peer Review Panel needs to give an in-depth review of the quality of water.

III. Back-pumping of polluted water into Lake Okeechobee by the SFWMD

In recent weeks, the SFWMD, twice, has back-pumped water polluted by nutrients and pesticides into Lake Okeechobee. I am aghast. It looks to me that the SFWMD should be setting the example for the rest of us.

IV. Wetlands

I am concerned that wetlands, the funnels of water life, are not getting more than a casual review by all entities in the Upper East Coast and probably the whole of the SFWMD.

I am requesting that the PEER REVIEW PANEL give great consideration to my concerns and any other point of view that has environmental sensitivities.

Sincerely,

Lloyd Brumfield

DRAFT

June 15, 2001

TO: Janet Llewellyn, Deputy Director,
Division of Water Resource Management

FROM: Dana C. Bryan, Chief
Bureau of Natural and Cultural Resources
Division of Recreation and Parks

SUBJECT: Draft Report for Minimum Flows and Levels for the St. Lucie River and Estuary

The Florida Department of Environmental Protection's Division of Recreation and Parks has reviewed the 21 May 2001 draft of the *Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary* produced by the South Florida Water Management District (SFWMD). The Division is involved because of the effects of the MFLs on St. Lucie Inlet Preserve State Park (SLI) which is under our management. We offer the following general comments, followed by specific comments.

General Comments:

The Division is charged with providing recreational opportunities on the lands it manages. SLI attracts 16,614 visitors annually (1999-00) and has a total direct economic impact on the local community of $564,608 annually. This visitation and economic impact depends on the continued preservation of the recreationally important natural resource attributes of the park, including the heavily dived offshore worm reef in the 3,888 acres of submerged park lands. Deterioration of the ecology and aesthetics of the preserve and reef are serious concerns that might affect tourists and the local community.

The Division is also charged with conserving the natural values in parks. SLI is one of only 15 preserves in the 155-unit Florida State Park system. The designation of state preserves is special to those lands where preservation of representative samples of Florida's natural conditions is given priority over recreational user considerations. Uses allowed are primarily passive and related to the aesthetic, educational, and scientific enjoyment of the conditions maintained in the preserve.

The Florida Environmental Reorganization Act of 1993 requires FDEP to develop and implement measures to "...protect the functions of entire ecological systems through enhanced coordination of public land acquisition, regulatory and planning programs". The acquisition of both SLI and the adjacent Seabranch State Preserve on the other side of the Indian River Lagoon provides a perfect example of this ecosystem protection in Florida State Parks. These two units provide a complete cross-section of the Atlantic Coastal Ridge from sand pine scrub to scrubby flatwoods, mesic flatwoods, baygall, and estuarine tidal swamp, then across the lagoon to a barrier island with sub-tropical maritime hammock, coastal beach, and an offshore Pleistocene reef.

The Division also is compelled by Florida Statute 258.037 to establish a policy "to acquire typical portions of the original domain of the state...of such character as to emblemize the state's natural values; conserve these natural values for all time....to enable the people of Florida and visitors to enjoy these values without depleting them..." The Division believes that it is imperative, if we are to adhere to our statutory charge, that the water necessary to sustain the habitat be maintained or where possible restored.

The Division feels that the MFLs in state parks should be established under the direction of Section 373.042 (1), F.S., which states that the water management districts "...shall also consider, and at their discretion may provide for, the protection of non-consumptive uses in the establishment of minimum flows and levels...." Those non-consumptive uses are especially important on public lands and most important on Florida State Parks because of their clear public function of recreation, appreciation of the natural environment, and environmental education.

Florida State Parks will not continue to survive in this state if we cannot depend on the water management districts to protect and restore our state park water resources. Given that the State of Florida has invested over $1 billion to acquire these properties, it is in the public interest to protect and restore them.

Specific Comments:

We agree that the many species of fishes, invertebrates and wildlife, including commercially and recreationally important and listed species, depend on the oligohaline habitat that exists in the St. Lucie Estuary. While fresh water flows from both the North and South Forks of the St. Lucie River are necessary for the viability of the estuary, historical documentation shows the need for a balanced approach to the management of these flows. The estuary experiences harm both from a lack of freshwater (less than 21cfs in the North Fork and less than 7cfs in the South Fork) and from an overabundance of fresh water during discharges from Lake Okeechobee. The discharges from the lake are responsible for tons of sediment, nutrients, and other pollutant being introduced into the estuary and the offshore reef. The chemical composition and turbidity of these discharges need to be quantified and the discharges' harmful effects need to be addressed in order for us to protect the park's reef and near shore habitats.

We are unable to determine whether the proposed MFL regime is healthy for the preserve and offshore reef, but our collective goal should be to restore as nearly as possible the historic flows regime.

DCB/mh

cc: Fran Mainella, Director, Division of Recreation and Parks
Mike Bullock, Assistant Director, Division of Recreation and Parks
George Jones, District 5 Bureau Chief
Pete Scalco, OMC Manager, District 5
John Griner, Manager, St. Lucie Inlet Preserve State Park

Department of
Environmental Protection

Jeb Bush
Governor

Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

David B. Struhs
Secretary

June 27, 2001

Ms. Kathy LaMartina
South Florida Water Management District
P. O. Box 24680
West Palm Beach, Florida 33416-4680

Re: St. Lucie River and Estuary Minimum Flow

Dear Ms. La Martina:

The Department appreciates the opportunity to comment on the District's technical document describing the methodology used to develop a minimum flow and level (MFL) for the St. Lucie River and Estuary. The District has correctly pointed out that much of the harm occurring to the St. Lucie Estuary is a result of too much fresh water flowing into the river during certain times. However, the District also recognizes the need to establish a MFL while fresh water resources are still available in the area. The District's various water supply plans and related studies have indicated that the region's consumptive uses will increase substantially. Establishing a MFL now, before fresh water is diverted to other uses, will provide the District with a valuable decision tool when managing the water resources of the region.

We agree that maintaining a certain amount of oligohaline habitat within the estuary during low flow conditions is the best approach for establishing a MFL in the system. The technical analysis of the North Fork does a good job of relating flows, salinity, and extent of oligohaline habitat. Even though various assumptions were needed to conduct the North Fork analysis, it is clear how the District determined that a flow of 70 cfs was needed to maintain the oligohaline habitat at a certain reach within the river.

However, we are concerned that the District's current definition of significant harm for the estuary does not adequately correlate with maintaining the salinity at a concentration that will allow a desired amount of oligohaline habitat to persist. As we understand the document, the proposed MFL for the St. Lucie Estuary will be the point at which:

> "freshwater flows to the estuary are less than the rate of evaporation for a period of two consecutive months during the dry season for two or more years in succession."

This does not represent an actual flow and it is difficult to understand how this will be established and implemented. It appears that the District only used flows generated by the Natural Systems Model to establish this level and could not correlate this flow with salinity and extent of oligohaline habitat. While it appears that the District is lacking a great deal of information to make these correlations, we believe the District could establish an initial MFL that represents a quantified amount of flow. The District's analysis has shown that a flow of 70 cfs is needed within the North Fork to protect the

"More Protection, Less Process"

Printed on recycled paper.

oligohaline habitat from significant harm and has estimated that the South Fork would need a flow of 27 cfs. Thus, it may be possible to simply establish two separate MFLs, one for the North and South forks respectively that will assure an adequate supply of fresh water for the estuary.

During the District's recent efforts related to the Caloosahatchee River and Estuary, the District initially used a definition for significant harm that was not an actual flow, but eventually revised their definition so it identified a specific salinity target that was associated with a specific flow during the dry season. We recommend that the District revise the St. Lucie MFL in a similar manner.

Additionally we are concerned with the relationship of this MFL to water quality within the system and the relationship between the findings in this report and those of the Indian River Lagoon Feasibility Study. The technical report describes the water quality problems associated with the system and indicates that this is a SWIM waterbody, which is scheduled for TMDL establishment, yet there is no correlation between the MFL selection and the expected impacts this would have on water quality. The District should clearly show that the MFL established would not worsen water quality problems in the river and estuary.

The technical document (page 2-27) indicates the Indian River Lagoon Feasibility Study (IRLFS) has identified target fresh water flows of 350 to 2,000 cfs. The low flow target established by the IRLFS is significantly different from the one described in the MFL technical document. The District should clearly explain the discrepancies between these two studies. Furthermore, it might be more appropriate for the MFL to be established closer to 350 cfs.

We appreciate the opportunity to work with the District on these important efforts. With a few modifications suggested above, we believe that an adequate MFL can be established for the St. Lucie system in spite of the lack of comprehensive data. As knowledge is obtained, the District can modify the MFL accordingly, but as the District correctly points out, it is important to establish the best MFL possible at this point before the pressures of consumptive uses cause harm to the system. If you have any additional questions, please contact Kathleen Greenwood at 488-0784.

Sincerely,

for

Kathleen P. Greenwood
Senior Management Analyst II
Office of Water Policy

JGL/kpg
cc:

Tom Swihart, DEP
Melissa Meeker, DEP
Pam McVety, DEP
Dana Bryan, DEP
Frank Metzler, DEP
John Outland, DEP
Cheryl McKee, DEP
Danny Riley, DEP
Rick Hicks, DEP
Gary Roderick, DEP

2 of 2

Date: June 27, 2001

To: Kathy LaMartina e-mail klamart@sfwmd.gov 1-800-432-2047 x6325
Program Manager, District-wide MFL Program
South Florida Water Management District
3301 Gun Club Rd.
West Pam Beach, FL 33406

From: Mark D. Perry, Executive Director
Florida Oceanographic Society
890 NE Ocean Blvd.
Stuart, FL 34996

RE: "Technical Document to Support Development of Minimum Flows for the St. Lucie River and Estuary" SFWMD Water Supply Division, DRAFT May 21, 2001

The document seems to be an attempt to provide a technical justification for developing minimum flows and levels as required by Section 373 F.S.. As stated on page 1-4 "The overall purpose of Chapter 373 is to ensure the sustainability of water resources of the state (Section 373.016, F.S.)." Yet on page 1-1 it is stated that "Establishing minimum flows and levels alone will not be sufficient to maintain a sustainable resource or protect it from significant harm during the broad range of water conditions occurring in the managed system."

As the definition indicates, "**minimum flow**" is the "minimum flow limit at which further withdrawls would be significantly harmful to the water resources or ecology of the area" and "**minimum level**" is the level of groundwater in an aquifer and the level of surface water at which further withdrawls would be significantly harmful to the water resources of the area". This Section makes sense when applied to groundwater aquifers and lakes or streams that are used for water supply. Minimum flows and levels are set to control withdrawls that would degrade the water resource on supply side, but these terms are confusing when addressing a natural estuarine system such as the St. Lucie River Estuary.

The application of Minimum Flows and Levels (MFL) also becomes especially difficult to apply to the St. Lucie River Estuary when addressing the issues of the "Levels of Harm" such as "Harm, Significant Harm and Serious Harm" and the concept of "Recovery and Prevention Strategy" as outlined on pages 1-5 thru 1-7. The St. Lucie Estuary watershed has already experienced "Significant or Serious Harm" from the implementation of major canals and water management systems that drain the lands for agriculture and have significantly lowered the natural water table. And how is the "Recovery and Prevention Strategy" coincide with the Upper East Coast Water Supply Plan that is looking to supply all future water needs through the Floridan Aquifer because we have seriously altered the surficial or Shallow Aquifer System?

In the Water Resources section starting on page 2-15, the 3rd paragraph seems accurate when stating, "The construction and operation of surface water management systems affect the quantity and distribution of recharge to the Shallow Aquifer System". It further states that " the surface water management systems within the planning area function primarily as aquifer drains". Agricultural drainage and residential development have extensively modified the watershed of the St. Lucie Estuary resulting in a lowered groundwater table and negative quality, quantity and timing of water entering the Estuary.

Beginning in the Resource Protection Programs section under Indian River Lagoon Feasibility Study page 2-27 the conclusions begin to draw that "inflow targets of 350 to 2,000 cfs for the Estuary will provide the baseline assumptions for the Minimum Flow and Level technical criteria". Further on at the Summary and Conclusions of Chapter 3, page 3-6 it is stated "Determination of the lower limit of flows that constitute significant harm to this riverine system, will be linked to the maintenance of salinity levels". There seems to be a definite move here to somehow control and manipulate the inflows to the Estuary to maintain a "minimum" on the perceived "salinity envelope". Does this suggest that if the salinities in the Estuary get too high, the District will open up the gates and flow more polluted water through canals into the Estuary just to maintain a "salinity envelope" under the disguise of a "minimum flow and level" criteria?

A big problem in the this report is in the Conclusions and Recommendations starting on page 5-19 when the terms "Harm" and "Significant Harm" are redefined using a comparison of freshwater inflows to the Estuary with rates of evaporation over set periods of time. Why is this so much different than the original definitions in Chapter 373 FS? It is also concluded that 70 cfs may be an appropriate management target for the river and flows below 21 cfs occur when "significant harm" is occurring in the Estuary. These are very interesting numbers and I suppose they come right out of the models, but is this really a management tool for the Estuary? Are we going to further manipulate the watershed by releasing polluted water from canals into the Estuary to maintain a "salinity level or envelope"? What about working to restore the water tables in the watershed and getting at the source of the issues in drainage and regulation schedule releases from Lake Okeechobee? I am surprised they didn't use Chapter 373 to maintain "minimum flows and levels" in the canals for the 130 large agricultural consumption permits who pump water out for irrigation. The heavy use of the Floridan Aquifer by both agriculture and the projected heavy use for future potable water supplies may have profound affects on our groundwater resources, which in turn will impact our surface water use in canals and the St. Lucie River Estuary.

ST. LUCIE RIVER INITIATIVE

P.O. Box 2082 Stuart, FL 34995 561/287-8158 FAX 561/286-7188

June 27, 2001

Kathy La Martina
Program Manager, MFL
South Florida Water Mgmt. District

RE: Minimum flows for the St. Lucie River and Estuary

Dear Kathy:

While we generally support the District's recommendations on low flows for the St. Lucie we do have some misgivings and some questions.

At present your discussion is reasonably flexible, (pp1-1, 1-2, Draft of May 21). "Setting a minimum flow is viewed as a starting point to define minimum water needs for sustain ability", p.1-1. Will that same spirit survive imminent rule development and eventual legal wording? In the next few years of experience will review and change be reasonably possible?

We have misgivings that the latest modeling may suggest too low a minimum for the long-term health of the river. Your creation of the latest natural systems model conflicts with a long-held belief - that in its heyday the river received, in dry times, a larger flow than it does today. With the new NSM the reverse is true, Fig. 5-5. We are still struggling to accept that.

We are concerned that the recommended minimum flow - 70 CFS - might lead to greater use-permitting. This could become critical when the CERP process is completed in our two counties in 2007 (?). Then the water in the river, and in the new storage system, will be cleaner, and more attractive.

With the request that you consider most carefully our questions, concerns, and misgivings, we support your plan. You should move forward with it. For our part we will raise our level of cooperative watchfulness with you.

MISSION: To restore the St. Lucie River to health & productivity through private & public action.

I like your report. The draft of May 21st and the appendices are a well written account of high technical quality. It's going to join a small group of District reports that I will refer to over the years for insight and information.

Sincerely,

Max Quackenbos
For The river Initiative.

P.S. Thank you for accommodating my input at the last moment. To be blunt I forgot the date. M.

Cc: Kevin Henderson
Bud Jordan
Ed Weinberg
Patti Sime SFWMD local

APPENDIX K
DRAFT PRELIMINARY WATER CONTROL PLAN FOR THE TEN MILE CREEK DEEP WATER STORAGE AREA

Four permanent structures will be constructed as part of the Ten Mile Creek Deep Water Storage Area (DWSA). These structures consist of two pump stations, S-382 and S383; a culvert, S-384; and an emergency spillway. The main pump station, S-382, will pump water from Ten Mile Creek into the DWSA. The S-383 pump station will deliver water into the treatment cell by the use of gravity flow or a small pump. The S-384 culvert will be used for treatment cell outfall. The emergency spillway will be located near the main pump station, and is intended to relieve the DWSA in the event of severe storms. This draft plan describes the proposed operating criteria for these structures.

The Ten Mile Creek DWSA is part of the Ten Mile Creek Critical Project, which is ranked as the eleventh most important project of the 34 proposed critical projects. This project is located in St. Lucie County, southwest of Fort Pierce. It is situated just south of State Road 70 (Okeechobee Road) and west of the intersection of I-95 and the Florida Turnpike and north of Midway Road. The project is located at the outlet of the 30,682-acre (48-square mile) Ten Mile Creek basin.

GENERAL OBJECTIVES

This preliminary water control plan focuses on how the project will operate during the operational testing and monitoring phase of the project. This plan includes the flexibility to make incremental changes to the proposed optimum canal elevations, the DWSA, and the treatment cells throughout the testing period in order to achieve desired project benefits while maintaining the existing level of flood protection in the Ten Mile Creek basin.

The Ten-Mile Creek Reservoir/Stormwater Treatment Area (referred to from this point on as the treatment cell) will restore two degraded features of the North Fork St. Lucie River basin: water storage and nutrient demand. Restoring these features will result in a more natural pattern of freshwater flows into the estuary, more natural (lower) volumes of runoff leaving the basin, and reduced nutrient loads leaving the basin.

The Ten Mile Creek DWSA will provide additional water storage to the basin. Rapid pumping to and slow drainage from the reservoir mimics the behavior of shallow surface storage that has been lost through development over the years. When operated correctly, the reservoir reduces runoff from most storm events and helps restore the historic flow pattern of fresh water entering the estuary. Water stored in the reservoir will also reduce total runoff leaving the basin and simultaneously reduce demands on the Floridan aquifer. The reservoir and the adjoining treatment marsh will improve downstream water quality by filtering runoff and removing suspended sediments, phosphorous, and nitrogen.

The operations of the DWSA facilities are expected to maximize prestorm available storage, maximize dry season water supply, and maximize treatment of basin runoff. These are competing objectives that must be balanced through the operating rules. Achieving an optimal balance will require adjustments in the operating rules to incorporate improvements in the understanding of watershed hydrology, local water management, and regional water management. Current hydrologic analyses indicate the optimal balance occurs when pumps try to capture 50 percent of storm runoff (minus base flow) and when dry-season releases to the filter marsh decrease with decreasing storage.

This preliminary water control plan focuses on how the project will operate during the operational testing and monitoring phase of the project. This plan includes the flexibility to make incremental changes to the proposed optimum canal elevations, the DWSA, and the treatment cells throughout the testing period in order to achieve desired project benefits while maintaining the existing level of flood protection in the Ten Mile Creek basin.

FEATURES

This project consists of a DWSA storage area and an adjacent treatment cell. The DWSA will have 500 acres of effective storage area and the treatment cell will have roughly 160 acres of treatment area. The DWSA and the treatment cell will have a total storage capacity of approximately 6,000 acre-feet.

Water will inflow into the DWSA system via the S-382 pump station that is located on the northern levee adjacent to the creek. S-382 will have a total pumping capacity of 380-cubic feet per second (cfs). It will have three pumps. One will have a pumping capacity of 60 cfs and two will each have a pumping capacity of 160 cfs. In addition, the pump station will have a return bay with a 100-cfs capacity for flows from the DWSA back to the creek. An overflow weir set at an elevation of 29.75 feet National Geodetic Vertical Datum of 1929 (NGVD) will also be included on the northern side of the project adjacent to the creek for emergency flows.

The outflow structure, for the DWSA, the S-383 pump station, will consist of a 40-cfs control structure that will usually pass water by gravity from the DWSA to the treatment cell. When the DWSA drops below the bottom elevation of the treatment cell (17.0 feet NGVD), the gravity control structure will not be able to transfer flows. Two pumps have been included to ensure that water can flow out of the structure when it falls below this elevation. The two small pumps will have pumping capacities of 15 and 25 cfs.

The outflow structure for the treatment cell, the S-384 culvert, will consist of a 100-cfs gravity controlled structure that will flow into Canal 96 of the North St. Lucie River Water Control District. From this point, the water will flow north in Canal 96 and discharge downstream of the existing Gordy Road control structure on the eastern end of Ten Mile Creek. This control structure is owned and operated by the NSLRWCD.

The Gordy Road control structure, known as S-71-1 by NSLRWCD, is the easternmost water control structure. It is a 4-bay radial gate spillway. The outside gates are two 18-foot wide radial gates, with a crest elevation of 9.3 feet NGVD and inverts of the gates are at an elevation of 3.0 feet NGVD. The inside gates are two 18-foot wide radial gates, with a crest elevation of 10.0 feet NGVD and inverts of the gates are also at an elevation of 3.0 feet NGVD. This structure is generally operated to maintain an upstream pool elevation of 9.5 to 10.5 feet NGVD. Additional operating details for this structure and other pertinent structures operated by NSLRWCD can be found by contacting the NSLRWCD office at (561)-461-5050.

The Ten Mile Creek Project must maintain the current level of flood protection in the Ten Mile Creek drainage basin. Also, it should not impact the normal operations of the NSLRWCD.

OVERALL PLAN FOR WATER CONTROL

The development of the operational plan being proposed was dependent on the determination of optimum water elevations in the canals, the DWSA, and the treatment cells. To determine the optimum elevation, a preliminary analysis of daily stage data at the Gordy Road control structure was done. The investigation revealed that water levels upstream of the Gordy Road structure are typically maintained between 9.5 and 10.5 feet NGVD.

Guidelines for S-382 and S-383

The operating criteria for the pump stations are based on water elevations. The elevations were determined by using discharge rating curves that calculated discharges. The rating curves were developed by applying field measurements taken by the South Florida Water Management District (SFWMD) to a theoretical “over the top flow” equation. The field measurements were used to calibrate the coefficient of discharge, C_d, in **Equation (K-1)**.

$$Q = C_d L \sqrt{2gH_g}^3 \qquad \text{(K-1)}$$

NEED TO DEFINE PARAMETERS IN THE EQUATION

S-382

The discharge rating curve used to calculate discharges at the Gordy Road control structure **Table K-1**. The rating curve is developed only for water that would be discharged without any gate openings by the NSLRWCD.

Table K-1. Discharge Rating Curve for the S-382 Pump Station

Elevation at Gordy Road Structure (feet NGVD)	Discharge (Q) (cfs)
9	0.00
9.1	0.00
9.2	0.00
9.3	0.78
9.4	5.88
9.5	13.50
9.6	22.97
9.7	33.98
9.8	46.35
9.9	59.94
10	76.24
10.1	95.28
10.2	117.94
10.3	144.05
10.4	172.79
10.5	203.83
10.6	236.96
10.7	272.04
10.8	308.94
10.9	347.56
11	387.82

The base flow runoff for the Gordy Road control structure is 15 cfs. Since capturing the base flow is not an objective of this project, the turn on criteria for flows that exceed base flow conditions should be a headwater stage that will allow 15 cfs of water per day to pass over the Gordy Road structure, while capturing 50 percent of the water that exceeds the base flow and storing it in the DWSA. To ensure a smoother transition when capturing this excess flow, pump 1 should only be turned on part of the day.

Based on the discharge rating curve, at a headwater elevation of 9.7 feet NGVD, approximately 34 to 35 cfs of water will pass over the Gordy Road structure. If pump 1, with a pumping capacity of 60 cfs, is running 8 hours per day, it would be delivering discharges equivalent to 20 cfs per day into the DWSA and the equivalent of 15 cfs per day would continue to pass over the Gordy Road structure. Therefore, pump 1 should only be turned on 8 hours each day when the elevation of water is between 9.7 and 10.1 feet NGVD.

The NSLRWCD will maintain its normal operations during runoff events, which means that the Gordy Road structure will begin pumping if the headwater reaches 11.0 feet NGVD. Therefore, S-382 should be operating at full capacity when the canal reaches 10.8 feet NGVD. The S-382 pumping station capacity will be 380 cfs. If the DWSA reaches the maximum storage capacity of 29.75 feet NGVD, then pumping at S-382 should stop.

S-382 Turn On Criteria

The S-382 turn on criteria during a runoff event are as follows:

1. If the water level increases to an elevation of 10.1 feet NGVD, pump 1 should be turned on.
2. If the water level increases to an elevation of 10.6 feet NGVD, pump 2 should be turned on.
3. If the water level increases to an elevation of 10.8 feet NGVD, pump 3 should be turned on.

S-382 Turn Off Criteria

The S-382 turn off criteria as water levels recede are as follows:

1. If the water level recedes to an elevation of 10.7 feet NGVD, pump 3 should be turned off.
2. If the water level recedes to an elevation of 10.3 feet NGVD, pump 2 should be turned off.
3. If the water level recedes to an elevation of 9.7 feet NGVD, pump 1 should be turned off.

Cooperation with the NSLRWCD

By operating the pump station using this criteria, the pumps will be at full capacity before NSLRWCD begins operating the Gordy Road structure. The elevation at which the structure will begin operating is approximately 11 feet NGVD.

The NSLRWCD office may request water from the DWSA be returned to the Ten Mile Creek Canal for agricultural use. If the headwater water level at the S-382 pump station is below 9.0 feet NGVD, then the discharge culvert at S-382 should be opened to refill the canal until it reaches the optimum level of 9.5 feet NGVD. This is subject to the availability of water. Although not being a project purpose, this action might temporarily help satisfy agricultural demands, especially in the dry season, while maintaining the integrity of the project.

The NSLRWCD has agreed that existing operating conditions at the Gordy Road Water Control Structure will remain unchanged. Changes should not be required, since the operation described above will actually reduce the number of gate changes needed at the Gordy Road structure.

The NSLRWCD will maintain its normal operations during runoff events, which means that the Gordy Road structure will begin pumping if the headwater reaches 11.0 feet NGVD. Therefore, S-382 should be operating at full capacity when the canal reaches 10.8 feet NGVD.

The S-382 pumping station capacity will be 380 cfs. If the DWSA reaches the maximum storage capacity of 29.75 feet NGVD, then pumping at S-382 should stop.

S-383

The discharge rating curve used to calculate discharges at the headwater of the DWSA are presented in **Tables K-2** and **K-3**. **Table K-2** presents the wet season curve while **Table K-3** presents the dry season curve.

Table K-2. Discharge Rating Curve for the S-383 Pump Station during the Wet Season

Elevation at DWSA Headwater (feet NGVD)	DWSA Discharge (Q) (cfs)
13.0	0
14.0	6
15.0	14
16.0	23
17.0	33
18.0	35
19.0	35
20.0	35
21.0	35
22.0	35
23.0	35
24.0	35
25.0	35
26.0	35
27.0	35
28.0	35
29.0	35

Table K-3. Discharge Rating Curve for the S-383 Pump Station during the Dry Season

Elevation at DWSA Headwater (feet NGVD)	DWSA Discharge (Q) (cfs)
13.0	0
14.0	4
15.0	9
16.0	14
17.0	21
18.0	28
19.0	35
20.0	35
21.0	35
22.0	35
23.0	35
24.0	35
25.0	35
26.0	35
27.0	35
28.0	35
29.0	35

The following operating guidelines should be used for the S-383 outflow structure. Based on the difficulty of accessing S-383, gate or pump operational changes should not be made more than once a week.

S-383 Operating Guidelines for the Wet Season

The wet season begins in June and ends in November. The operating guidelines for S-383 during the wet season are as follows:

1. If the water level in the DWSA increases to 14.0 feet NGVD, discharge 6 cfs of water to the treatment cell.
2. If the water level in the DWSA increases to 15.0 feet NGVD, discharge 14 cfs of water to the treatment cell.
3. If the water level in the DWSA increases to 16.0 feet NGVD, discharge 23 cfs of water to the treatment cell.
4. If the water level in the DWSA increases to 17.0 feet NGVD, discharge 33 cfs of water to the treatment cell.
5. If the water level in the DWSA increases to 18.0 feet NGVD or over, discharge 35 cfs of water to the treatment cell.

S-383 Operating Guidelines for the Dry Season

The dry season begins in December and ends in May. The operating guidelines for S-383 during the dry season are as follows:

1. If the water level in the DWSA increases to 14.0 feet NGVD, discharge 4 cfs of water to the treatment cell.
2. If the water level in the DWSA increases to 15.0 feet NGVD, discharge 9 cfs of water to the treatment cell.
3. If the water level in the DWSA increases to 16.0 feet NGVD, discharge 14 cfs of water to the treatment cell.
4. If the water level in the DWSA increases to 17.0 feet NGVD, discharge 21 cfs of water to the treatment cell.
5. If the water level in the DWSA increases to 18.0 feet NGVD, discharge 28 cfs of water to the treatment cell.
6. If the water level in the DWSA increases to 19.0 feet NGVD, discharge 35 cfs of water to the treatment cell.

S-384 Operating Guidelines

If water is available, the S-384 culvert should be operated to maintain the equivalent of 3 feet of water storage in the treatment cell. The goal is to make water available for releases for environmental enhancement. The operation of this structure is based on the optimum water storage capacity of 3 feet shown by a model developed by the SFWMD. MORE INFO ON MODEL.

Spillway Operating Guidelines

The spillway surcharge elevation is 31.6 feet NGVD with a discharge capacity of about 1,440 cfs. If the spillway overflows, S-383 and S-384 shall be closed to avoid worsening existing conditions.

OTHER EFFECTS OF THE WATER CONTROL PLAN

Recreation. The water management operations do not include those specifically designed for the benefit of recreational activities within the Ten Mile Creek Project area.

Water Quality. The intent of the Ten Mile Creek DWSA project is to attenuate stormwater flows into the North Fork of the St. Lucie River. These flows, which originate in the Ten Mile Creek basin, are to be captured and stored in the DWSA and subsequently pumped into a treatment pond before release back into the creek. The resulting hydrodynamic, physical, and biological treatment is expected to ultimately result in the reduction of undesirable freshwater loads being delivered to the St. Lucie Estuary. CITE

THE ENVIRONMENTAL ASSESSMENT FOR THE “TEN MILE CREEK WATER PRESERVE AREA CRITICAL PROJECT” (CALL OUT).

Fish and Wildlife in the DWSA. The fish and wildlife resources in the footprint of the DWSA will change from citrus grove fauna to an open water system. Prey fish species such as centarchids (sunfish) and mosquito fish will quickly colonize the DWSA. As the DWSA levels decrease these fish can act as forage for wading birds, raccoons and other small mammals, and other organisms. The DWSA will also support reptiles and amphibians including salamanders and turtles. CITE THE ENVIRONMENTAL ASSESSMENT FOR THE “TEN MILE CREEK WATER PRESERVE AREA CRITICAL PROJECT”.

Fish and Wildlife in the Treatment Cell. The treatment cell fauna will stay the same with possibly the addition of a number of organisms suited for shallow water conditions (3 to 4 feet). Since these conditions currently exist in the wetlands of the treatment cell, increased numbers will occur because of a potentially larger amount of this type of habitat.

Fish and Wildlife in the St. Lucie Estuary and the Indian River Lagoon. The St. Lucie Estuary, which is downstream of the project, will help restore the St. Lucie Estuary to a healthy and sustainable ecosystem. With a decrease in the size and frequency of freshwater pulses, the waters of the estuary should become clearer and more saline. The estuary is expected to then be able to support shoal grass and oysters and other typical elements of the estuarine fauna. In order to fully restore the Indian River Lagoon, however, the proposed project will have to act as one part of the improvements recommended in the *Indian River Lagoon Feasibility Study* (CITATION), in order to fully return the St. Lucie Estuary to a healthy ecosystem and ultimately maximize estuarine benefits. Once the St. Lucie Estuary is restored, the Indian River Lagoon system in that area should yield secondary benefits to the nearby seagrass.

Water Supply. Water supply will not be affected by the water control plan. Water pumped into the DWSA would be storm water normally lost to tide. Local ground water recharge would be expected to increase, possibly offsetting some effects of agricultural withdrawals on adjoining lands.

Prestorm Canal Drawdown. When heavy rainfall is anticipated in the Ten Mile Creek basin from tropical storms, hurricanes, and other extreme rainfall events, water levels will be drawn down as much as practicable in order to allow for the maximum amount of canal and ground water storage.

Seepage Control. If the criteria for pumping has been met, any seepage lost through the levee around the impoundment will be recaptured with pump operations.

APPENDIX L
SELECTED PASSAGES FROM THE FLORIDA STATUTES AND FLORIDA ADMINISTRATIVE CODE

SELECTED PASSAGES FROM CHAPTER 373, FLORIDA STATUTES

Source: http://www.leg.state.fl.us/statutes on October 16, 2001

373.016 Declaration of policy.--

(1) The waters in the state are among its basic resources. Such waters have not heretofore been conserved or fully controlled so as to realize their full beneficial use.

(2) The department and the governing board shall take into account cumulative impacts on water resources and manage those resources in a manner to ensure their sustainability.

(3) It is further declared to be the policy of the Legislature:

(a) To provide for the management of water and related land resources;

(b) To promote the conservation, replenishment, recapture, enhancement, development, and proper utilization of surface and ground water;

(c) To develop and regulate dams, impoundments, reservoirs, and other works and to provide water storage for beneficial purposes;

(d) To promote the availability of sufficient water for all existing and future reasonable-beneficial uses and natural systems;

(e) To prevent damage from floods, soil erosion, and excessive drainage;

(f) To minimize degradation of water resources caused by the discharge of stormwater;

(g) To preserve natural resources, fish, and wildlife;

(h) To promote the public policy set forth in s. 403.021;

(i) To promote recreational development, protect public lands, and assist in maintaining the navigability of rivers and harbors; and

(j) Otherwise to promote the health, safety, and general welfare of the people of this state.

In implementing this chapter, the department and the governing board shall construe and apply the policies in this subsection as a whole, and no specific policy is to be construed or applied in isolation from the other policies in this subsection.

(4)(a) Because water constitutes a public resource benefiting the entire state, it is the policy of the Legislature that the waters in the state be managed on a state and regional basis. Consistent with this directive, the Legislature recognizes the need to allocate water throughout the state so as to meet all reasonable-beneficial uses. However, the Legislature acknowledges that such allocations have in the past adversely affected the water resources of certain areas in this state. To protect such water resources and to meet the current and future needs of those areas with abundant water, the Legislature directs the department and the water management districts to encourage the use of water from sources nearest the area of use or application whenever practicable. Such sources shall include all naturally occurring water sources and all alternative water sources, including, but not limited to, desalination, conservation, reuse of nonpotable reclaimed water and stormwater, and aquifer storage and recovery. Reuse of potable reclaimed water and stormwater shall not be subject to the evaluation described in s. 373.223(3)(a)-(g). However, this directive to encourage the use of water, whenever practicable, from sources nearest the area of use or application shall not apply to the transport and direct and indirect use of water within the area encompassed by the Central and Southern Florida Flood Control Project, nor shall it apply anywhere in the state to the transport and use of water supplied exclusively for bottled water as defined in s. 500.03(1)(d), nor shall it apply to the transport and use of reclaimed water for electrical power production by an electric utility as defined in section 366.02(2).

(b) In establishing the policy outlined in paragraph (a), the Legislature realizes that under certain circumstances the need to transport water from distant sources may be necessary for environmental, technical, or economic reasons.

(5) The Legislature recognizes that the water resource problems of the state vary from region to region, both in magnitude and complexity. It is therefore the intent of the Legislature to vest in the Department of Environmental Protection or its successor agency the power and responsibility to accomplish the conservation, protection, management, and control of the waters of the state and with sufficient flexibility and discretion to accomplish these ends through delegation of appropriate powers to the various water management districts. The department may exercise any power herein authorized to be exercised by a water management district; however, to the greatest extent practicable, such power should be delegated to the governing board of a water management district.

(6) It is further declared the policy of the Legislature that each water management district, to the extent consistent with effective management practices, shall approximate its fiscal and budget policies and procedures to those of the state.

History.--s. 2, part I, ch. 72-299; s. 36, ch. 79-65; s. 70, ch. 83-310; s. 5, ch. 89-279; s. 20, ch. 93-213; s. 250, ch. 94-356; s. 1, ch. 97-160; s. 1, ch. 98-88.

373.036 Florida water plan; district water management plans.--

(1) FLORIDA WATER PLAN.--In cooperation with the water management districts, regional water supply authorities, and others, the department shall develop the Florida water plan. The Florida water plan shall include, but not be limited to:

(a) The programs and activities of the department related to water supply, water quality, flood protection and floodplain management, and natural systems.

(b) The water quality standards of the department.

(c) The district water management plans.

(d) Goals, objectives, and guidance for the development and review of programs, rules, and plans relating to water resources, based on statutory policies and directives. The state water policy rule, renamed the water resource implementation rule pursuant to s. 373.019(20), shall serve as this part of the plan. Amendments or additions to this part of the Florida water plan shall be adopted by the department as part of the water resource implementation rule. In accordance with s. 373.114, the department shall review rules of the water management districts for consistency with this rule. Amendments to the water resource implementation rule must be adopted by the secretary of the department and be submitted to the President of the Senate and the Speaker of the House of Representatives within 7 days after publication in the Florida Administrative Weekly. Amendments shall not become effective until the conclusion of the next regular session of the Legislature following their adoption.

(2) DISTRICT WATER MANAGEMENT PLANS.--

(a) Each governing board shall develop a district water management plan for water resources within its region, which plan addresses water supply, water quality, flood protection and floodplain management, and natural systems. The district water management plan shall be based on at least a 20-year planning period, shall be developed and revised in cooperation with other agencies, regional water supply authorities, units of government, and interested parties, and shall be updated at least once every 5 years. The governing board shall hold a public hearing at least 30 days in advance of completing the development or revision of the district water management plan.

(b) The district water management plan shall include, but not be limited to:

1. The scientific methodologies for establishing minimum flows and levels under s. 373.042, and all established minimum flows and levels.

2. Identification of one or more water supply planning regions that singly or together encompass the entire district.

3. Technical data and information prepared under ss. 373.0391 and 373.0395.

4. A districtwide water supply assessment, to be completed no later than July 1, 1998, which determines for each water supply planning region:

a. Existing legal uses, reasonably anticipated future needs, and existing and reasonably anticipated sources of water and conservation efforts; and

b. Whether existing and reasonably anticipated sources of water and conservation efforts are adequate to supply water for all existing legal uses and reasonably anticipated future needs and to sustain the water resources and related natural systems.

5. Any completed regional water supply plans.

(c) If necessary for implementation, the governing board shall adopt by rule or order relevant portions of the district water management plan, to the extent of its statutory authority.

(d) In the formulation of the district water management plan, the governing board shall give due consideration to:

1. The attainment of maximum reasonable-beneficial use of water resources.

2. The maximum economic development of the water resources consistent with other uses.

3. The management of water resources for such purposes as environmental protection, drainage, flood control, and water storage.

4. The quantity of water available for application to a reasonable-beneficial use.

5. The prevention of wasteful, uneconomical, impractical, or unreasonable uses of water resources.

6. Presently exercised domestic use and permit rights.

7. The preservation and enhancement of the water quality of the state.

8. The state water resources policy as expressed by this chapter.

(3) The department and governing board shall give careful consideration to the requirements of public recreation and to the protection and procreation of fish and wildlife. The department or governing board may prohibit or restrict other future uses on certain designated bodies of water which may be inconsistent with these objectives.

(4) The governing board may designate certain uses in connection with a particular source of supply which, because of the nature of the activity or the amount of water required, would constitute an undesirable use for which the governing board may deny a permit.

(5) The governing board may designate certain uses in connection with a particular source of supply which, because of the nature of the activity or the amount of water required, would result in an enhancement or improvement of the water resources of the area. Such uses shall be preferred over other uses in the event of competing applications under the permitting systems authorized by this chapter.

(6) The department, in cooperation with the Executive Office of the Governor, or its successor agency, may add to the Florida water plan any other information, directions, or objectives it deems necessary or desirable for the guidance of the governing boards or other agencies in the administration and enforcement of this chapter.

History.--s. 6, part I, ch. 72-299; ss. 2, 3, ch. 73-190; s. 122, ch. 79-190; s. 3, ch. 97-160; s. 7, ch. 98-88; s. 164, ch. 99-13.

373.0361 Regional water supply planning.--

(1) By October 1, 1998, the governing board shall initiate water supply planning for each water supply planning region identified in the district water management plan under s. 373.036, where it determines that sources of water are not adequate for the planning period to supply water for all existing and projected reasonable-beneficial uses and to sustain the water resources and related natural systems. The planning must be conducted in an open public process, in coordination and cooperation with local governments, regional water supply authorities, government-owned and privately owned water utilities, self-suppliers, and other affected and interested parties. A determination by the governing board that initiation of a regional water supply plan for a specific planning region is not needed pursuant to this section shall be subject to s. 120.569. The governing board shall reevaluate such a determination at least once every 5 years and shall initiate a regional water supply plan, if needed, pursuant to this subsection.

(2) Each regional water supply plan shall be based on at least a 20-year planning period and shall include, but not be limited to:

(a) A water supply development component that includes:

1. A quantification of the water supply needs for all existing and reasonably projected future uses within the planning horizon. The level-of-certainty planning goal associated with identifying the water supply needs of existing and future reasonable-beneficial uses shall be based upon meeting those needs for a 1-in-10-year drought event.

2. A list of water source options for water supply development, including traditional and alternative sources, from which local government, government-owned and privately owned utilities, self-suppliers, and others may choose, which will exceed the needs identified in subparagraph 1.

3. For each option listed in subparagraph 2., the estimated amount of water available for use and the estimated costs of and potential sources of funding for water supply development.

4. A list of water supply development projects that meet the criteria in s. 373.0831(4).

(b) A water resource development component that includes:

1. A listing of those water resource development projects that support water supply development.

2. For each water resource development project listed:

a. An estimate of the amount of water to become available through the project.

b. The timetable for implementing or constructing the project and the estimated costs for implementing, operating, and maintaining the project.

c. Sources of funding and funding needs.

d. Who will implement the project and how it will be implemented.

(c) The recovery and prevention strategy described in s. 373.0421(2).

(d) A funding strategy for water resource development projects, which shall be reasonable and sufficient to pay the cost of constructing or implementing all of the listed projects.

(e) Consideration of how the options addressed in paragraphs (a) and (b) serve the public interest or save costs overall by preventing the loss of natural resources or avoiding greater future expenditures for water resource development or water supply development. However, unless adopted by rule, these considerations do not constitute final agency action.

(f) The technical data and information applicable to the planning region which are contained in the district water management plan and are necessary to support the regional water supply plan.

(g) The minimum flows and levels established for water resources within the planning region.

(3) Regional water supply plans initiated or completed by July 1, 1997, shall be revised, if necessary, to include a water supply development component and a water resource development component as described in paragraphs (2)(a) and (b).

(4) Governing board approval of a regional water supply plan shall not be subject to the rulemaking requirements of chapter 120. However, any portion of an approved regional water supply plan which affects the substantial interests of a party shall be subject to s. 120.569.

(5) By November 15, 1997, and annually thereafter, the department shall submit to the Governor and the Legislature a report on the status of regional water supply planning in each district. The report shall include:

(a) A compilation of the estimated costs of and potential sources of funding for water resource development and water supply development projects, as identified in the water management district regional water supply plans.

(b) A description of each district's progress toward achieving its water resource development objectives, as directed by s. 373.0831(3), including the district's implementation of its 5-year water resource development work program.

(6) Nothing contained in the water supply development component of the district water management plan shall be construed to require local governments, government-owned or privately owned water utilities, self-suppliers, or other water suppliers to select a water supply development option identified in the component merely because it is identified in the plan. However, this subsection shall not be construed to limit the authority of the department or governing board under part II.

History.--s. 4, ch. 97-160.

373.042 Minimum flows and levels.--

(1) Within each section, or the water management district as a whole, the department or the governing board shall establish the following:

(a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

(b) Minimum water level. The minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area.

The minimum flow and minimum water level shall be calculated by the department and the governing board using the best information available. When appropriate, minimum flows and levels may be calculated to reflect seasonal variations. The department and the governing board shall also consider, and at their discretion may provide for, the protection of nonconsumptive uses in the establishment of minimum flows and levels.

(2) By July 1, 1996, the Southwest Florida Water Management District shall amend and submit to the department for review and approval its priority list for the establishment of minimum flows and levels and delineating the order in which the governing board shall establish the minimum flows and levels for surface watercourses, aquifers, and surface water in the counties of Hillsborough, Pasco, and Pinellas. By November 15, 1997, and annually thereafter, each water management district shall submit to the department for review and approval a priority list and schedule for the establishment of minimum flows and levels for surface watercourses, aquifers, and surface waters within the district. The priority list shall also identify those water bodies for which the district will voluntarily undertake independent scientific peer review. By January 1, 1998, and annually thereafter, each water management district shall publish its approved priority list and schedule in the Florida Administrative Weekly. The priority list shall be based upon the importance of the waters to the state or region and the existence of or potential for significant harm to the water resources or ecology of the state or region, and shall include those waters which are experiencing or may reasonably be expected to experience adverse impacts. The priority list and schedule shall not be subject to any proceeding pursuant to chapter 120. Except as provided in subsection (3), the development of a priority list and compliance with the schedule for the establishment of minimum flows and levels pursuant to this subsection shall satisfy the requirements of subsection (1).

(3) Minimum flows or levels for priority waters in the counties of Hillsborough, Pasco, and Pinellas shall be established by October 1, 1997. Where a minimum flow or level for the priority waters within those counties has not been established by the applicable deadline, the secretary of the department shall, if requested by the governing body of any local government within whose jurisdiction the affected waters are located, establish the minimum flow or level in accordance with the procedures established by this section. The department's reasonable costs in establishing a minimum flow or level shall, upon request of the secretary, be reimbursed by the district.

(4)(a) Upon written request to the department or governing board by a substantially affected person, or by decision of the department or governing board, prior to the establishment of a minimum flow or level and prior to the filing of any petition for administrative hearing related to the minimum flow or level, all scientific or technical data, methodologies, and models, including all scientific and technical assumptions employed in each model, used to establish a minimum flow or level shall be subject to independent scientific peer review. Independent scientific peer review means review by a panel of independent, recognized experts in the fields of hydrology, hydrogeology, limnology, biology, and other scientific disciplines, to the extent relevant to the establishment of the minimum flow or level.

(b) If independent scientific peer review is requested, it shall be initiated at an appropriate point agreed upon by the department or governing board and the person or persons requesting the peer review. If no agreement is reached, the department or governing board shall determine the appropriate point at which to initiate peer review. The members of the peer review panel shall be selected within 60 days of the point of initiation by agreement of the department or governing board and the person or persons requesting the peer review. If the panel is not selected within the 60-day period, the time limitation may be waived upon the agreement of all parties. If no waiver occurs, the department or governing board may proceed to select the peer review panel. The cost of the peer review shall be borne equally by the district and each party requesting the peer review, to the extent economically feasible. The panel shall submit a final report to the governing board within 120 days after its selection unless the deadline is waived by agreement of all parties. Initiation of peer review pursuant to this paragraph shall toll any applicable deadline under chapter 120 or other law or district rule regarding permitting, rulemaking, or administrative hearings, until 60 days following submittal of the final report. Any such deadlines shall also be tolled for 60 days following withdrawal of the request or following agreement of the parties that peer review will no longer be pursued. The department or the governing board shall give significant weight to the final report of the peer review panel when establishing the minimum flow or level.

(c) If the final data, methodologies, and models, including all scientific and technical assumptions employed in each model upon which a minimum flow or level is based, have undergone peer review pursuant to this subsection, by request or by decision of the department or governing board, no further peer review shall be required with respect to that minimum flow or level.

(d) No minimum flow or level adopted by rule or formally noticed for adoption on or before May 2, 1997, shall be subject to the peer review provided for in this subsection.

(5) If a petition for administrative hearing is filed under chapter 120 challenging the establishment of a minimum flow or level, the report of an independent scientific peer review conducted under subsection (4) is admissible as evidence in the final hearing, and the administrative law judge must render the order within 120 days after the filing of the petition. The time limit for rendering the order shall not be extended except by agreement of all the parties. To the extent that the parties agree to the findings of the peer review, they may stipulate that those findings be incorporated as findings of fact in the final order.

History.--s. 6, part I, ch. 72-299; s. 2, ch. 73-190; s. 2, ch. 96-339; s. 5, ch. 97-160.

373.0421 Establishment and implementation of minimum flows and levels.--

(1) ESTABLISHMENT.--

(a) *Considerations.*--When establishing minimum flows and levels pursuant to s. 373.042, the department or governing board shall consider changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of an affected watershed, surface water, or aquifer, provided that nothing in this paragraph shall allow significant harm as provided by s. 373.042(1) caused by withdrawals.

(b) *Exclusions.*--

1. The Legislature recognizes that certain water bodies no longer serve their historical hydrologic functions. The Legislature also recognizes that recovery of these water bodies to historical hydrologic conditions may not be economically or technically feasible, and that such recovery effort could cause adverse environmental or hydrologic impacts. Accordingly, the department or governing board may determine that setting a minimum flow or level for such a water body based on its historical condition is not appropriate.

2. The department or the governing board is not required to establish minimum flows or levels pursuant to s. 373.042 for surface water bodies less than 25 acres in area, unless the water body or bodies, individually or cumulatively, have significant economic, environmental, or hydrologic value.

3. The department or the governing board shall not set minimum flows or levels pursuant to s. 373.042 for surface water bodies constructed prior to the requirement for a permit, or pursuant to an exemption, a permit, or a reclamation plan which regulates the size, depth, or function of the surface water body under the provisions of this chapter, chapter 378, or chapter 403, unless the constructed surface water body is of significant hydrologic value or is an essential element of the water resources of the area.

The exclusions of this paragraph shall not apply to the Everglades Protection Area, as defined in s. 373.4592(2)(h).

(2) If the existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level established pursuant to s. 373.042, the department or governing board, as part of the regional water supply plan described in s. 373.0361, shall expeditiously implement a recovery or prevention strategy, which includes the development of additional water supplies and other actions, consistent with the authority granted by this chapter, to:

(a) Achieve recovery to the established minimum flow or level as soon as practicable; or

(b) Prevent the existing flow or level from falling below the established minimum flow or level.

The recovery or prevention strategy shall include phasing or a timetable which will allow for the provision of sufficient water supplies for all existing and projected reasonable-beneficial uses, including development of additional water supplies and implementation of conservation and other efficiency measures concurrent with, to the extent practical, and to offset, reductions in permitted withdrawals, consistent with the provisions of this chapter.

(3) The provisions of this section are supplemental to any other specific requirements or authority provided by law. Minimum flows and levels shall be reevaluated periodically and revised as needed.

History.--s. 6, ch. 97-160.

373.223 Conditions for a permit.--

(1) To obtain a permit pursuant to the provisions of this chapter, the applicant must establish that the proposed use of water:

(a) Is a reasonable-beneficial use as defined in s. 373.019;

(b) Will not interfere with any presently existing legal use of water; and

(c) Is consistent with the public interest.

(2) The governing board or the department may authorize the holder of a use permit to transport and use ground or surface water beyond overlying land, across county boundaries, or outside the watershed from which it is taken if the governing board or department determines that such transport and use is consistent with the public interest, and no local government shall adopt or enforce any law, ordinance, rule, regulation, or order to the contrary.

(3) Except for the transport and use of water supplied by the Central and Southern Florida Flood Control Project, and anywhere in the state when the transport and use of water is supplied exclusively for bottled water as defined in s. 500.03(1)(d), any water use permit applications pending as of April 1, 1998, with the Northwest Florida Water Management District and self-suppliers of water for which the proposed water source and area of use or application are located on contiguous private properties, when evaluating whether a potential transport and use of ground or surface water across county boundaries is consistent with the public interest, pursuant to paragraph (1)(c), the governing board or department shall consider:

(a) The proximity of the proposed water source to the area of use or application.

(b) All impoundments, streams, groundwater sources, or watercourses that are geographically closer to the area of use or application than the proposed source, and that are technically and economically feasible for the proposed transport and use.

(c) All economically and technically feasible alternatives to the proposed source, including, but not limited to, desalination, conservation, reuse of nonpotable reclaimed water and stormwater, and aquifer storage and recovery.

(d) The potential environmental impacts that may result from the transport and use of water from the proposed source, and the potential environmental impacts that may result from use of the other water sources identified in paragraphs (b) and (c).

(e) Whether existing and reasonably anticipated sources of water and conservation efforts are adequate to supply water for existing legal uses and reasonably anticipated future needs of the water supply planning region in which the proposed water source is located.

(f) Consultations with local governments affected by the proposed transport and use.

(g) The value of the existing capital investment in water-related infrastructure made by the applicant.

Where districtwide water supply assessments and regional water supply plans have been prepared pursuant to ss. 373.036 and 373.0361, the governing board or the department shall use the applicable plans and assessments as the basis for its consideration of the applicable factors in this subsection.

(4) The governing board or the department, by regulation, may reserve from use by permit applicants, water in such locations and quantities, and for such seasons of the year, as in its judgment may be required for the protection of fish and wildlife or the public health and safety. Such reservations shall be subject to periodic review and revision in the light of changed conditions. However, all presently existing legal uses of water shall be protected so long as such use is not contrary to the public interest.

History.--s. 3, part II, ch. 72-299; s. 10, ch. 73-190; s. 10, ch. 76-243; s. 35, ch. 85-81; s. 4, ch. 98-88.

373.246 Declaration of water shortage or emergency.--

(1) The governing board or the department by regulation shall formulate a plan for implementation during periods of water shortage. As a part of this plan the governing board or the department shall adopt a reasonable system of water-use classification according to source of water supply; method of extraction, withdrawal, or diversion; or use of water or a combination thereof. The plan may include provisions for variances and alternative measures to prevent undue hardship and ensure equitable distribution of water resources.

(2) The governing board or the department by order may declare that a water shortage exists for a source or sources within all or part of the district when insufficient water is or will be available to meet the present and anticipated requirements of the users or when conditions are such as to require temporary reduction in total use within the area to protect water resources from serious harm. Such orders will be final agency action.

(3) In accordance with the plan adopted under subsection (1), the governing board or the department may impose such restrictions on one or more classes of water uses as may be necessary to protect the water resources of the area from serious harm and to restore them to their previous condition.

(4) A declaration of water shortage and any measures adopted pursuant thereto may be rescinded by the governing board or the department.

(5) When a water shortage is declared, the governing board or the department shall cause notice thereof to be published in a prominent place within a newspaper of general circulation throughout the area. Publication of such notice will serve as notice to all users in the area of the condition of water shortage.

(6) The governing board or the department shall notify each permittee in the district by regular mail of any change in the condition of his or her permit or any suspension of his or her permit or of any other restriction on the permittee's use of water for the duration of the water shortage.

(7) If an emergency condition exists due to a water shortage within any area of the district, and if the department, or the executive director of the district with the concurrence of the governing board, finds that the exercise of powers under subsection (1) is not sufficient to protect the public health, safety, or welfare; the health of animals, fish, or aquatic life; a public water supply; or recreational, commercial, industrial, agricultural, or other reasonable uses, it or he or she may, pursuant to the provisions of s. 373.119, issue emergency orders reciting the existence of such an emergency and requiring that such action, including, but not limited to, apportioning, rotating, limiting, or prohibiting the use of the water resources of the district, be taken as the department or the executive director deems necessary to meet the emergency.

(8) An affected party to whom an emergency order is directed under subsection (7) shall comply immediately, but may challenge such an order in the manner set forth in s. 373.119.

History.--s. 10, part II, ch. 72-299; s. 14, ch. 78-95; s. 11, ch. 82-101; s. 10, ch. 84-341; s. 601, ch. 95-148; s. 168, ch. 99-13.

SELECTED PASSAGES FROM CHAPTER 40E-2, FLORIDA ADMINISTRATIVE CODE

Source: http://fac.dos.state.fl.us/fac/ on November 13, 2000

CHAPTER 40E-2 CONSUMPTIVE USE

40E-2.010 Review of Consumptive Use Permit Applications.
Consumptive use permit applications are processed pursuant to Section 120.60, F.S., Part VI of Chapter 40E-1, F.A.C., and Chapter 28-107, F.A.C.

Specific Authority 120.54(5), 120.60 FS. Law Implemented 120.54(5), 120.60 FS. History–New 7-2-98.

40E-2.011 Policy and Purpose.

(1) It is the policy of the District to control all water uses within its boundaries, pursuant to the provisions of Chapter 373, Florida Statutes, and Chapter 17-40 and Title 40E, F.A.C.

(2) The rules in this chapter implement the comprehensive water use permit system contemplated in Part II of Chapter 373, Florida Statutes.

(3) Additional rules relating to water use are found in Chapter 40E-20 (General Water Use Permits), Chapter 40E-21 (The Water Shortage Plan), Chapter 40E-22 (Regional Water Shortage Plans) and Chapter 40E-23 (Critical Water Supply Problem Areas).

(4) Standards for the construction, repair and abandonment of water wells are found in Chapter 40E-3 (Water Wells) and Chapter 40E-30 (General Permits for Water Wells).

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.103(1), 373.203, 373.216 – .249 FS. History–New 9-3-81, Formerly 16K-2.01, Amended 7-4-82, 2-24-85, 11-18-91.

40E-2.031 Implementation.

(1) The effective dates for the water use permitting program established in this chapter are:

(a) If the use or withdrawal of water exceeds 100,000 gallons per day, the effective dates are:

1. January 12, 1977, for the portion of the District formerly within the Ridge and Lower Gulf Coast Water Management District,

2. March 2, 1974, for the remainder of the District;

(b) If the use or withdrawal of water does not exceed 100,000 gallons per day, the effective date is January 14, 1979.

(2) The effective dates specified in subsection (1) are used to determine the two year period provided in Section 373.266, Florida Statutes, for existing water users to file initial applications.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.103(1), 373.216, 373.226 FS. History–New 9-3-81, Formerly 16K-2.011.

40E-2.041 Permits Required.

(1) Unless expressly exempt by law or District rule, a water use permit must be obtained from the District prior to any use or withdrawal of water.

(2) The District issues water use permits in two forms, individual water use permits and general water use permits. An individual water use permit may be obtained by meeting the requirements of this chapter. Chapter 40E-20 provides the requirements for qualifying for a general water use permit.

(3) Under certain circumstances the Board or the Executive Director may issue a temporary water use permit pursuant to Rule 40E-2.441 and Section 373.244, Florida Statutes.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.103(1), 373.219, 373.244 FS. History–New 9-3-81, Formerly 16K-2.03(1), (2).

40E-2.051 Exemptions.

No permit is required under Rule 40E-2.041 for the following water uses:

(1) Water used strictly for domestic use at a single family dwelling or duplex provided that the water is obtained from one withdrawal facility for each single family dwelling or duplex.

(2) Water used strictly for fire fighting purposes, and

(3) Water used at a single family dwelling or duplex including but not limited to home lawn and ornamental irrigation, car washing, and other incidental uses provided that the water is obtained from one withdrawal facility for each single family dwelling or duplex.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.219 FS. History–New 9-3-81, Formerly 16K-2.025, Amended 2-24-85, 4-20-94.

40E-2.091 Publications Incorporated by Reference.

(1) The "Basis of Review for Water Use Permit Applications within the South Florida Water Management District – October 1997", is hereby published by reference and incorporated into this chapter.

(2) The document listed in subsection (1) is published by the District and is available from the District upon request.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.219, 373.223, 373.224, 373.229, 373.232, 373.233, 373.236, 373.239 FS. History–New 9-3-81, Formerly 16K-2.035(1), Amended 2-24-85, 11-21-89, 1-4-93, 4-20-94, 11-26-95, 7-11-96, 4-9-97, 12-10-97.

40E-2.101 Content of Application.

(1) Applications for permits required by this chapter shall be filed with the District. The application shall contain:

(a) The following parts of Form 0645 Surface Water Management Permit Applications and/or Water Use Permit Applications, as incorporated by reference in Rule 40E-1.659;

1. Part RC-1A Administrative Information for Surface Water Management Permit Applications and/or Water Use Permit Applications;

2. Part RC-1W Application for a Water Use Permit;

(b) The appropriate permit application processing fee required by Rule 40E-1.607;

(c) The information required in subsection 373.229(1), Florida Statutes; and

(d) Information sufficient to show that the use meets the criteria and conditions established in Rule 40E-2.301.

(2) The application must be signed by the applicant or the authorized agent of the applicant.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.103(1), 373.219, 373.223, 373.229 FS. History–New 9-3-81, Amended 12-1-82, 2-24-85, 11-21-89, Repromulgated 1-4-93, Amended 4-20-94.

40E-2.301 Conditions for Issuance of Permits.

(1) In order to obtain a permit, permit renewal, or permit modification under this chapter, an applicant must give reasonable assurances that the proposed water use at the time the permit application is deemed complete:

(a) will not cause significant saline water intrusion;

(b) will not adversely impact offsite land uses;

(c) will not cause adverse environmental impacts;

(d) will not cause pollution of the water resources;

(e) is otherwise a reasonable-beneficial use as defined in subsection 373.019(4), Florida Statutes, with consideration given to the factors set forth in Rule 17-40.401(2);

(f) will not interfere with presently existing legal uses;

(g) is in accordance with the State Water Policy on water transport pursuant to Rule 17-40.402;

(h) makes use of a reclaimed water source unless the applicant, in any geographic location, demonstrates that its use is either not economically, environmentally or technically feasible; or in areas not designated as Critical Water Supply Problem Areas pursuant to Chapter 40E-23, F.A.C., the applicant demonstrates reclaimed water is not readily available; and

(i) is consistent with Sections 373.016, 373.036, Florida Statutes, and otherwise is consistent with the public interest as prescribed by Chapter 373 and this Chapter.

(2) In order to satisfy the conditions for permit issuance in subsection (1), the permit applicant must provide reasonable assurances that the criteria in the "Basis of Review for Water Use Permit Applications within the South Florida Water Management District – October 1997", incorporated by reference in Rule 40E-2.091(1), are met.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.023, 373.185, 373.219, 373.223, 373.226, 373.236 FS. History–New 9-3-81, Formerly 16K-2.035(2), Amended 2-24-85, 1-4-93, 4-20-94, 7-11-96, 4-9-97, 12-10-97.

40E-2.321 Duration of Permit.

(1) Unless revoked or otherwise modified, the duration of a water use permit issued pursuant to this chapter is the lesser of:

(a) The time period for which the permit applicant demonstrates that water will be available to meet the projected demands and during which the conditions for issuance of a permit in Rule 40E-2.301 will be met.

(b) The time period for which the permit applicant demonstrates legal control.

(2) In addition to the duration limitation in subsection (1) above, the permit durations for specific uses shall not exceed the following time periods:

(a) For public water supply and industrial water uses, the period shall not exceed 10 years.

(b) For dewatering water uses, the period shall not exceed 3 years.

(c) For irrigation uses, the period shall not exceed the basin expiration date as specified in the document described in Rule 40E-2.091 as applicable to the location of the project.

(d) For aquifer remediations, the period shall not exceed that required to complete the operation as specified in the Remedial Action Plan approved by the state or local agency having legal jurisdiction over such activities or 20 years, whichever is less.

(e) For all other uses, the period shall not exceed 10 years.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.236 FS. History–New 9-3-81, Amended 2-24-85, 4-20-94, 7-11-96.

40E-2.331 Modification of Permits.

(1) A permittee shall apply to the Board for approval of any modification of an unexpired permit pursuant to Section 373.239, Florida Statutes. The Executive Director shall initiate proceedings to modify a permit pursuant to Rule 40E-1.609, F.A.C.

(2) Applications for modification, except letter modifications issued pursuant to subsection (4), shall contain the information required in Rule 40E-2.101, will be evaluated using the criteria specified in Rule 40E-2.301 and will be subject to the limiting conditions specified in Rule 40E-2.381. Modifications shall be approved if criteria in Rule 40E-2.301 are met.

(3) Proposed increases in allocation will be treated as new uses to the extent the proposed allocation exceeds the existing allocation.

(4)(a) Modification of an existing water use permit shall be approved by letter, provided the permit is in compliance with all applicable limiting conditions and the modification request:

1. does not result in an increase in the amount of the permit allocation;

2. does not modify the existing permit expiration date, except that when the permit duration is based upon the current lease expiration date, the permit duration shall be extended by letter modification to the new lease date, but shall not exceed the applicable permit duration pursuant to Rule 40E-2.321;

3. does not potentially interfere with any presently existing legal use of water, cause adverse environmental impacts, saltwater intrusion, pollution of the water resources, adverse impacts to offsite land uses, or does not otherwise raise issues requiring a Staff determination of whether such impacts would occur pursuant to the "Basis of Review for Water Use Permit Applications within the South Florida Water Management District – October 1997", incorporated by reference in Rule 40E-2.091(1); and,

4. does not change the permitted withdrawal source(s) or use classification.

5. does not result in a modification of the permit which must be approved by the Governing Board pursuant to Section 373.239(2), F.S.

(b) The timeframes set forth in Rule 40E-1.606 shall apply to the processing of letter modifications.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.223, 373.229, 373.239 FS. History–New 9-3-81, Formerly 16K-2.09(1), Amended 4-20-94, 7-11-96, 4-9-97, 12-10-97.

40E-2.341 Revocation of Permits.

Violations of this chapter may result in the revocation or suspension of the authorization in whole or in part in accordance with the provisions of Chapter 373, including Sections 373.119 and 373.243, F.S., Chapter 120, F.S., and Rules 40E-1.609, and 28-107.004, F.A.C.

Specific Authority 373.044, 373.113 FS. Law Implemented 120.60(6), 373.103(4), 373.219, 373.229 FS. History–New 4-20-94, Amended 7-2-98.

40E-2.351 Transfer of Permits.
A permittee must comply with the requirements of Rule 40E-1.6107 in order to obtain a permit transfer to a new permittee. If the permit transfer is in conjunction with an application for permit modification, the permit shall be transferred at the time of permit modification if all applicable permit transfer criteria are met. Upon approval, all terms and conditions of the permit shall be binding on the transferee.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.223, 373.229, 373.239 FS. History–New 9-3-81, Formerly 16K-2.09(2), Amended 4-20-94.

40E-2.381 Limiting Conditions.
The Board shall impose on any permit granted under this chapter such reasonable standard and special permit conditions as are necessary to assure that the permitted use or withdrawal will be consistent with the overall objectives of the District, will not be harmful to the water resources of the District, is reasonable-beneficial, will not interfere with any presently existing legal uses, and is consistent with the public interest. Standard permit conditions in Section 5.1 of the "Basis of Review for Water Use Permit Applications within the South Florida Water Management District – October 1997", incorporated by reference in Rule 40E-2.091(1) shall be set forth in the permit. Special permit conditions, including those specified in Section 5.2 of the "Basis of Review for Water Use Permit Applications within the South Florida Water Management District – October 1997", shall be set forth in the permit.

Specific Authority 373.044, 373.113, 373.171 FS. Law Implemented 373.219(1) FS. History–New 9-3-81, Amended 2-24-85, 7-26-87, 4-20-94, 7-11-96, 4-9-97, 12-10-97.

40E-2.441 Temporary Permits.
The Board or the Executive Director may issue temporary water use permits under the provisions of Section 373.244, Florida Statutes.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.244 FS. History–New 9-3-81, Amended 4-20-94.

40E-2.451 Emergency Authorization.
(1) Permission to begin use, withdrawal, or diversion of water prior to the issuance of a permit may be applied for in writing, when emergency conditions exist which would justify such permission. However, no such permission shall be granted unless the use, withdrawal, or diversion is already being considered for a permit under Rule 40E-2.041. A serious set of unforeseen or unforeseeable circumstances must exist to create an emergency. Mere carelessness or lack of planning on the part of the applicant shall not be sufficient grounds to warrant the granting of emergency authorization.
(2) Emergency authorizations shall be administered pursuant to Rule 40E-1.6115, F.A.C.

Specific Authority 373.044, 373.113 FS. Law Implemented 120.60(5), 373.219 FS. History–New 9-3-81, Formerly 16K-2.11, Amended 4-20-94, 7-2-98.

40E-2.501 Permit Classification.
Each water use permit shall be classified according to source, use and method of withdrawal. The source use and method of withdrawal classes are listed in Rules 40E-21.611 through 40E-21.691.

Specific Authority 373.044, 373.113 FS. Law Implemented 373.246 FS. History–New 9-3-81, Formerly 16K-2.12(2), Amended 7-4-82.