Technical Documentation to Support Development of Minimum Flows and Levels for Florida Bay

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EXECUTIVE SUMMARY

Florida Bay has been identified by the South Florida Water Management District (SFWMD) as a priority water body and the District has recommended that Minimum Flow and Level (MFL) criteria should be established for this Bay by 2006. Initial technical steps in the MFL process include: (1) identification of Florida Bay's resources and functions, (2) surveying available information, (3) documenting historic conditions, (4) synthesizing and analyzing data to determine relationships between freshwater inflow and ecological responses, with the purpose of identifying threshold conditions (freshwater flow, water levels, salinity) that impact Florida Bay natural resources, such that recovery requires at least two years. From this technical analysis, in conjunction with other technical and policy considerations, a definition of significant harm and associated numeric criteria will be developed. This report presents information about steps 1 through 4.

The South Florida Water Management District staff's evaluation of the relationships between the hydrologic conditions of the southern Everglades and the resulting ecological status of the salinity transition zone and northeastern Florida Bay is described below. The report was peer-reviewed by an independent panel of scientists. Results of the peer review process were used to refine the technical evaluation, as appropriate, and the technical results that was ultimately used in the rule development process for identification of a Florida Bay "Minimum Flow and Level" (MFL) standard.

RESOURCES IN THE FLORIDA BAY TRANSITION ZONE

This report focuses on northeastern Florida Bay and its adjacent salinity transition zone (**Figure E-1**) because this area is sensitive to managed freshwater flow and our current modeling capability is largely limited to this portion of the Bay. This transition zone is characterized by a salinity gradient that ranges from predominantly fresh water and low salinity conditions at the northern boundary with Everglades marshes to predominantly marine waters at the southern boundary with northeastern Florida Bay. Most analyses in this report consider environmental conditions and ecological characteristics along a transect that extends from Taylor River at the upper (northern fresh water) edge of the transition zone, through a succession of brackish water channels and ponds in the saline wetlands, through a coastal embayment (Little Madeira Bay), to northeastern Florida Bay (Eagle Key Basin). This transect location was selected because it roughly follows a major path of freshwater flow delivered from the regional water management system into the northern end of Taylor Slough, toward the Taylor River and into Florida Bay. Furthermore, data availability is relatively high along this transect. The Taylor River site, located at the northern end of the transition zone – northeastern Bay transect, was selected as representative of the low-salinity wetlands of the transition zone, and also as an indicator site for the entire transition zone – northeastern Bay region.

A resource-based approach was applied to determine effects of reduced freshwater inflow and high salinity on plant and animal communities that live in the salinity transition zone and northeastern Florida Bay in order to identify thresholds that cause long term impacts (taking two years or more to recover to baseline character). Salinity along the study transect changes in response to local rainfall, upstream water management and water deliveries. A submersed aquatic vegetation (SAV) species, widgeon grass (*Ruppia maritima*), is identified as an important biological resource and an overall indicator of community health in this transition zone. Loss of SAV and macroalgae results in loss of habitat, shelter, and food for waterfowl, forage fishes and invertebrates; loss of productivity; destabilization of sediments; reduced nutrient retention; and water quality impacts throughout the transition zone.

Analysis of field data and results of modeling studies indicate that losses of all major SAV or macroalgal species and the ecological functions they serve are likely to occur in the transition zone when average salinity at the Taylor River site remains above 30 psu (practical salinity units) for periods of a month or more. SAV habitat in northeastern Florida Bay, downstream from the transition zone, is dominated by shoal grass (*Halodule wrightii*) and turtle grass (*Thalassia testudinum*). These species are more salinity tolerant than widgeon grass. Field and modeling studies also suggest that maintaining salinity less than 40 psu in northeastern Florida Bay prevents negative impacts, such as decreasing SAV species diversity, decreasing habitat quality, and decreasing fish and invertebrate resources. Based on these considerations, such impacts to resources across the transition zone and in northeastern Florida Bay will likely occur when average monthly salinity at the Taylor River site exceeds 30 psu. Long term impacts occur when monthly average salinity exceeds 30 psu during consecutive years.

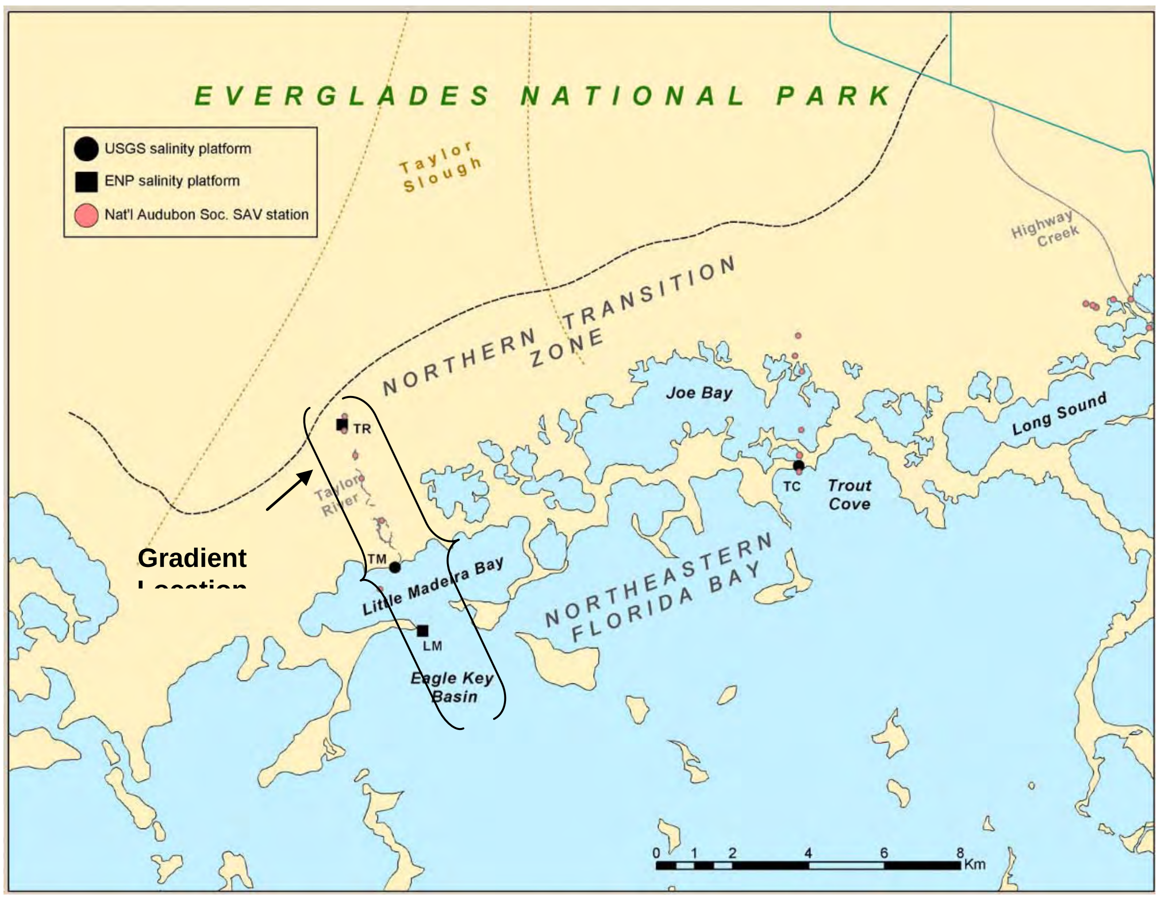


Figure E-1. Location and Major Features of Northeastern Florida Bay Showing: Locations of Taylor River, Taylor Slough and Other Creeks that Flow Across the Transition Zone.

DATA ANALYSIS AND OCCURRENCES OF RESOURCE IMPACTS

A mass balance hydrological model (FATHOM) was used in conjunction with field salinity measurements to simulate a 33-year historical record of inflows (1970-2002) and corresponding salinity for Florida Bay. In addition, a statistical multiple linear regression (MLR) model was developed and used in combination with field data to determine relationships among surface water levels, flow, and salinity in the transition zone and estimate salinity conditions in the transition zone during a similar historical time period. This timeframe included both low-flow and high-flow periods, resulting from climatic patterns as well as structural and operational changes in the water management system. This analysis of historical conditions indicated that monthly average salinity conditions exceeded 30 psu during 12 years of this 33-year period at the Taylor River site (at the northern end of the study transect), including several times when these high salinity conditions occurred during two or more consecutive years. Further analyses were conducted to estimate the volume of fresh water that was discharged toward Florida Bay during, and prior to, periods when salinity would likely exceed 30 psu at the Taylor River site. Salinity generally exceeded 30 psu at this site during periods when (a) total annual flows entering northeastern Florida Bay were less than 105,000 acre-ft, and /or (b) monthly average salinity at Taylor River exceeded 19 psu during January to March and total freshwater flows for three consecutive months prior to the salinity exceedance were less than 7,000 acre-ft.

RECOVERY AND PREVENTION STRATEGIES

These analyses suggest that once the criteria for significant harm have been formally established through the MFL rule development process, a number of steps could potentially be taken by water managers to decrease the occurrences of high salinity conditions (above 30 psu) at the Taylor River site. These actions will be defined in the final rule and technical documentation in terms of recovery strategies (if the MFL criteria are being exceeded under current conditions) or prevention strategies (if the MFL criteria are likely to be exceeded in the future).

As part of a continuing adaptive management program for this region, upstream flows, water levels and salinity at the Taylor River site, and SAV and macroalgal resources along the transect, should be continually monitored. Fresh water flows through the transition zone during very dry periods can potentially be managed to reduce or prevent high salinity conditions by providing additional water deliveries to Taylor Slough when sufficient good quality water is available. Future planning efforts and field tests should evaluate the feasibility and/or need for additional regional storage that may be needed to provide these increased flows.

CONCLUSIONS

- Submersed aquatic vegetation (SAV) and macroalgal habitat within the Taylor River/Little Madeira Bay/ Eagle Key gradient is responsive to conditions in the Everglades–Florida Bay Transition Zone; SAV and macroalgae is a critical component of the Florida Bay ecosystem.
- Freshwater discharges from the regional water management system have a direct effect on salinity conditions in the transition zone and also influence adjacent waters of northeastern Florida Bay.
- Widgeon grass *(Ruppia maritima)* is an indicator of SAV habitat and ecosystem status. *Ruppia* is responsive to salinity change in the transition zone and, compared to other SAV species in this zone, is tolerant of high salinity; when *Ruppia* is eliminated by high salinity, SAV habitat is lost. A threshold condition averaging above 30 psu for 30 days during two consecutive years is identified as a condition that causes a long term (requiring at least two years for recovery) impact on *Ruppia* and the ecosystem.
- High salinity conditions that cause loss of SAV in the transition zone results in loss of other resources and functions including loss of habitat; decreased productivity and food for waterfowl, forage fishes and invertebrates; destabilization of sediments; and reduced nutrient retention and water quality throughout the transition zone.
- Review of salinity relationships developed in the report shows that the freshwater flows needed to maintain the a salinity regime of less than 30 psu in the transition zone will also

sustain variable estuarine salinity less than 20 psu during the wet season and salinity less than 40 psu during the dry season in northeastern Florida Bay.

- The loss or degradation of ecological resources and functions in the transition zone and northeastern Florida Bay can be minimized by providing sufficient fresh water flow, including discharges from regional water management facilities that maintain monthly salinity at the Taylor River site below 30 psu.
- Historical conditions over a 33-year period from 1970-2002 were reconstructed using a combination of model simulations and field data to estimate how often monthly average salinity exceeded 30 psu at the Taylor River monitoring site. Results of this analysis also provide a basis for comparison with proposed future recovery or prevention strategies, operational changes and/or restoration plans.
- Periods when monthly average salinity at Taylor River exceeded 30 psu generally corresponded to regional droughts or prolonged periods of low flow conditions. Over a 33-year period of reconstructed salinity conditions, 12 years had at least one month with an average salinity at Taylor River above 30 psu. Over this 33-year period, there were six periods when these high salinity conditions occurred in two or more consecutive years.
- High salinity (> 30 psu) generally occurred in the transition zone during periods when salinity at the Taylor River site were elevated (19 psu or higher) at the beginning of the calendar year, local rainfall was below normal and total freshwater flows were reduced.
- This analysis also showed that during periods when monthly average salinity at the Taylor River site exceeded 30 psu during successive years, salinity downstream in Little Madeira Bay and Eagle Key Basin were considerably higher and persisted for much longer periods. When salinity at Taylor River during drought periods exceeded 30 psu for 2-5 months, salinity in Little Madeira Bay and Eagle Key remained above 30 psu for a year or more and were above 40 psu (hypersaline) for several months.
- The relationships defined in this document provide quantitative information that can be used to help define flow conditions that are likely to result in significant harm to resources in the Everglades–Florida Bay Transition Zone and adjacent waters of northeastern Florida Bay.
- The volumes, spatial distribution and seasonal timing of inflows to northeastern Florida Bay should be included as elements to be further investigated in the Florida Keys and Florida Bay Feasibility Study (FBFKFS) and projects associated with the Comprehensive Everglades Restoration Plan (CERP).
- Any proposed MFL should be evaluated for consistency with existing and proposed MFLs for other water bodies within the regional system, including Everglades National Park.
- The District should continue support for ongoing investigations to gain a better understanding of the relationships between water levels at various sites in the Everglades, C-111 Basin and Florida Bay salinity.
- Conclusions from this investigation should be further refined and tested with newer and better data and modeling tools as these become available.
- Effects of salinity exposure on SAV, fishes and invertebrates need further investigation
- Monitoring of flow, salinity and the response of submersed aquatic vegetation and animal communities in the Taylor River and adjacent waters of northeastern Florida Bay should continue.

TECHNICAL SUMMARY

The Lower East Coast Regional Water Supply Plan identified Florida Bay as a priority water body for development of Minimum Flow and Level (MFL) criteria. In 2005, the MFL Priority List was updated to indicate that MFL criteria for Florida Bay would be established in 2006. This document summarizes technical analyses conducted by the SFWMD to support the development of MFL criteria for northeastern Florida Bay. Initial technical steps in the MFL process include: (1) identification of Florida Bay's resources and functions, (2) surveying available information, (3) documenting historic conditions, and (4) synthesizing and analyzing data to determine relationships between freshwater inflow and impacts on the Bay's resources for the purpose identifying threshold conditions (freshwater flow, water levels, salinity) that impact Florida Bay natural resources, such that recovery requires at least two years. From this technical analysis, in conjunction with other technical and policy considerations, a definition of significant harm and associated numeric criteria will be developed. This report describes scientific information that comprises steps 1 through 4.

Florida Bay is a shallow estuary (average depth <1 meter) at the extreme southern end of the Florida peninsula, bounded on east and south by the islands of the Florida Keys, on the north by the Everglades, and on the west by an open-water interface with the Gulf of Mexico. The Bay is largely within Everglades National Park and located in Miami-Dade and Monroe counties. The interior of the Bay is dominated by a complex array of small islands, mud banks, and seagrass beds that restrict circulation of water. The primary sources of freshwater input to northeastern Florida Bay are rainfall and flow from the Everglades watershed, including discharges from the regional water management system, through a major slough system (Taylor Slough), adjacent wetlands of the southeastern Everglades (the C-111 Canal basin), and tidal creeks.

Despite a history of research and monitoring activities within Florida Bay, quantitative information directly linking the responses of Florida Bay biota to changes in salinity or freshwater inflow had not been synthesized at the onset of this MFL effort. Several studies were therefore initiated to accomplish technical analyses supporting MFL development. These studies focused on resources within northeastern Florida Bay that are influenced by water management activities. A mass-balance hydrologic model, statistical flow/salinity relationships in the transition zone, a dynamic seagrass model, and statistically-based higher trophic level species models were enveloped. Data collection will continue and models will be further developed over the next several years in support of the Comprehensive Everglades Restoration Plan (CERP), including the Florida Bay and Florida Keys Feasibility Study (FBFKFS), which are evaluating the restoration needs of the Bay. These efforts will also provide greater predictive capability for future MFL evaluations.

This report provides a description of the water body (Chapter 2), the resources that need to be protected (Chapter 3), relationships that were used to define resource impacts (Chapter 4), how these relationships can be used to help develop MFL criteria (Chapter 5).

APPROACH

A number of possible approaches and options were considered as a means to support the development of MFL criteria for Florida Bay. A resource-based approach was applied, using a submersed aquatic vegetation (SAV) species, widgeon grass (*Ruppia maritima*), as an indicator of the salinity transition zone. This zone is defined as the wetland region between the Everglades and Florida Bay, where the fresh water of the Everglades mixes with the saline water of northeastern Florida Bay. Furthermore, this study utilized a gradient approach, evaluating environmental conditions and hydrologic-ecologic relations along a transect from the northern boundary of the transition zone into northeastern Florida Bay. The extent to which resources in the northeastern Bay depend on an estuarine condition and the adequacy of a transition zone indicator (*Ruppia*) to protect the conditions in the Bay proper were also examined. The selected transect follows a major route of freshwater flow from the Taylor Slough, which receives water from the southeastern portion of the SFWMD canal system, to Florida Bay. Furthermore, monitoring of flow, salinity, SAV and macroalgae along the transect has been ongoing as part of cooperative efforts among various Federal, State, and local agencies, along with universities and non-governmental organizations.

This report focuses on three regions along the Everglades–Florida Bay transect. The Taylor River site is representative of the northern transition zone, a region that commonly has fresh or oligohaline conditions and supports a mixture of biota, ranging from species common in the Everglades (e.g. sawgrass) to species common in Florida Bay (e.g. red mangrove). Little Madeira Bay is a representative coastal embayment that receives inflow from Taylor Slough, commonly has polyhaline to marine conditions, and supports a mixture of biota ranging from species common in the transition zone (e.g. widgeon grass) to species common in Florida Bay (e.g. turtle grass). The endpoint of the gradient is located within the Eagle Key Basin, which is representative of most of northeastern Florida Bay and contains SAV communities typical of the Bay as a whole (dominated by turtle grass). Salinity and biota in all three regions respond to freshwater inflow from creeks and overland sheet flow. Biological resources in fresh-to-brackish water portions of the transect are particularly sensitive to changes in freshwater inflow. The relationships among freshwater inflow, salinity, and impacts to resources were used to identify threshold flow and salinity levels that correspond with long term impacts to SAV.

A statistical (multiple linear regression) model was used to estimate the relationship between Everglades water levels and salinity in the transition zone. Additionally, a mass balance model (FATHOM) was used to simulate historical inflows and salinity responses in northeastern Florida Bay. Both modeling approaches, combined with available historical field data, were used to reconstruct salinity conditions during a 33-year time period (1970-2002) that includes both drought conditions and changes in water management in the basin. Results of these analyses identified those periods when elevated salinity conditions and impacts to SAV and macroalgal resources historically occurred within the transition zone and the associated salinity conditions in northeastern Florida Bay. The effects of these salinity conditions on seagrass and animal species in northeastern Florida Bay were then assessed using a combination of available field observations and predictive ecological modeling tools.

RESOURCES ALONG THE GRADIENT

The Everglades–Florida Bay transition zone is an ecotone containing numerous creeks, ponds, lakes, and wetlands that include mangrove swamps and saline marshes. Hydrologic conditions in this zone are influenced by sheet flow and seepage of fresh water from the Everglades and by intrusion of saline water from Florida Bay, as driven by wind and tide.

Wetlands at the boundary of the Bay, and bordering numerous mangrove creeks and ponds within about five kilometers of the Bay, are dominated by *Rhizophora mangle* (red mangrove) trees. Toward the interior of the transition zone, marshes contain a mixture of mangrove shrubs and grasses. Much of this zone has low productivity and sparse vegetation. *Cladium jamaicense* (sawgrass) dominates the freshwater boundary of the transition zone.

Transition zone wetlands provide habitat for the endangered American crocodile, which relies on the presence of estuarine conditions for part of its life cycle. These wetlands are also important foraging areas for various species of mammals such as raccoons, and for wading birds, such as the roseate spoonbill. Studies in the transition zone wetlands have shown that the density and biomass of forage fish tend to decrease during periods with low water levels and high salinity and increase with longer, more stable hydroperiods and reduced salinity. Foraging success of wading birds is highly dependent on declining water levels in the early dry season, which concentrate prey for these birds.

Aquatic biological communities that occur along the salinity gradient within the Everglades–Florida Bay transition zone include SAV and macroalgal communities that range from freshwater species such as bladderwort (*Utricularia* spp.) to oligohaline species (dominated by widgeon grass, *Ruppia maritima*) in transition zone ponds. Mixed seagrass (dominated by shoal grass, *Halodule wrightii* and turtle grass, *Thalassia testudinum*) are found in the northeastern coastal embayments and Florida Bay, proper. Within freshwater-to-oligohaline sections of the transition zone, widgeon grass is the predominant dominant vascular plant in the SAV community. These plants support an abundance of fish and invertebrate species that depend on the vegetation for food and shelter.

Within the more saline regions of northeastern Florida Bay, shoal grass and turtle grass become the dominant SAV species. Seagrasses are not only a highly productive foundation of the food web, but are also a principal habitat for higher trophic levels and a controller of water quality. Seagrass provides refuge, spawning or nursery area, and a food source for numerous important fish and invertebrate species. Spotted sea trout (*Cynoscion nebulosus*), gray snapper *(Lutjanus griseus*), red drum (*Sciaenops ocellatus*), snook (*Centropomus undecimalis*), striped mullet (*Mugil cephalus*), bay anchovy *(Anchoa mitchelli*), and a variety of forage fishes are permanent or transient residents in Florida Bay. Pink shrimp (*Farfantepenaeus duorarum*) and the spiny lobster (*Panulirus argus*) use much of Florida Bay as a primary nursery ground.

The SAV community along the gradient from Taylor River to Eagle Key Basin is a critical component of the regional ecosystem. This community includes a diversity of species, the most prominent of which are widgeon grass, shoal grass and turtle grass. These SAV species support key ecological functions of the Florida Bay estuarine ecosystem; they provide habitat, shelter, and food for waterfowl, forage fishes and invertebrates; primary and secondary productivity; substrate stabilization; nutrient retention; and water quality benefits.

DETERMINING EFFECTS OF SALINITY ON FLORIDA BAY RESOURCES

The technical information presented in Chapter 4 will be used as a basis to help define “significant harm” and appropriate water level and flow criteria to prevent significant harm. This technical information base is derived from literature reviews, field data and observations, small scale and mesocosm experiments, and numerical modeling. Two types of seagrass models (statistical and dynamic) were used to assess responses of indicator SAV communities over the historical period. Widgeon grass (*Ruppia maritima*) was selected as an indicator species for the transition zone and links were defined between the health of this species, the condition of the overall SAV community at the northern end of the transition zone and effects on downstream coastal embayments and seagrasses in Florida Bay. *Ruppia* is the most salt-tolerant SAV species in the transition zone. When salinity concentrations are too high to support *Ruppia*, then the entire SAV community in the transition zone, the habitat function provided by this community, and the associated plants and animals that depend on this habitat are also lost. Impacts are also likely to occur in marine seagrass communities located further downstream in northeastern Florida Bay.

Empirical evidence suggests that *Ruppia* is eliminated from transition zone waters when salinity exceeds 30 psu for about 30 days. This loss of *Ruppia* is likely due to mortality of seedlings and adult plants, as well as inhibition of seed germination and reproductive success above this salinity level. A threshold condition averaging above 30 psu for 30 days during two consecutive years is identified as a condition that causes a long term impact on *Ruppia* and the ecosystem.

Results of laboratory, modeling and field studies indicate that in the coastal embayments and open waters of northeastern Florida Bay, turtle grass (*Thalassia)* is likely to become dominant under sustained hypersaline conditions (above 40 psu), whereas shoal grass (*Halodule*) becomes dominant under sustained mesohaline conditions (less than 18 psu). The quantitative and qualitative composition of the SAV and macroalgal community, in turn, may impact many fish and invertebrate species within Florida Bay. Ecological models were used to characterize the sensitivity of various animals to salinity and to habitat quality within northeastern Florida Bay. Recent literature and research were reviewed to characterize organisms that used these zones and their salinity tolerances. Model analyses were then performed to assess the combined effects of salinity and changes in SAV and macroalgal habitat on animal assemblages. Salinity has a significant (though widely varying) effect on these species. Most of these fauna benefit from increased SAV cover. Analyses indicate that as salinity in the Bay increases from mesohaline toward marine and hypersaline conditions, overall abundance of the forage base (small animals that are food for larger fish, particularly sport fish) decreases. These changes occur due to direct salinity effects on fauna and indirect effects of SAV habitat loss. In particular, results indicate that the qualitative composition of SAV habitat affects higher trophic level species; loss of *Halodule* with prolonged hypersalinity appears to be detrimental to the faunal assemblage. Maintaining estuarine salinity (less than marine levels) conditions will thus protect a higher quality SAV habitat and its associated animal communities.

FINDINGS RELEVANT TO SELECTING MFL CRITERIA

A minimum flow or level is defined by Ch.373.0421 (1) F.S. as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area”. In developing minimum flows and levels for water bodies within the jurisdiction of the District, the agency adopted a narrative definition of “significant harm.” Significant harm is defined in Ch 40E-8 F.A.C. as the temporary loss of water resource functions which result from a change in surface or ground water hydrology that takes more than two years to recover. The specific water resource functions addressed by a MFL and the duration of the recovery period associated with significant harm are defined for each priority water body based on the MFL technical support document and summarized in Chapter 40E-8.

The specific technical analysis under review focuses on relatively low flow and high salinity conditions and attempts to identify thresholds of salinity exposure that impact ecological structure or function of valued ecosystem components such that recovery of these attributes is likely to span at least two years. The purpose of the Technical Support Document is to document the scientific or technical concepts (including scientific strategies to determine MFLs), data, methodologies, assumptions, inferences, and conclusions that may ultimately be used to develop the proposed MFL criteria, based on the best available information.

The requirement that the level of resource impact associated with significant harm take more than two years to recover is a guide only, and is intended to indicate that “significant harm” is not an impact level that occurs under average or natural hydrologic conditions. Instead, “significant harm” refers to effects that occur during dry hydrologic conditions at a level and frequency as a result of man-made withdrawals that cause increasingly severe, cumulative effects on water resources, e.g. if an exceedance of the threshold condition reoccurs within an interval that is shorter than the time needed for that resource to recover.

In this technical report, resource impacts that can be used as the basis for defining significant harm and MFL criteria for Florida Bay were identified. Highlights of these findings include:

- SAV and macroalgal habitat within the Taylor River/Little Madeira Bay/ Eagle Key gradient is an important feature of the Florida Bay ecosystem that is influenced by freshwater discharges from the regional water management system.
- The availability and qualitative structure of this habitat are suitable indicators of the overall health of the entire transition zone and adjacent northeastern Florida Bay ecosystem.
- *Ruppia* is proposed as an indicator of the status of the transition zone for MFL determination. Impacts to *Ruppia* and other resources occur when monthly average salinity exceeds 30 psu at the Taylor River site. Field and laboratory studies indicate that such a salinity exposure is associated with loss of *Ruppia* cover and SAV habitat in the transition zone.
- Long term impacts to *Ruppia* and SAV habitat are likely to occur when average salinity exceeds 30 psu for at least one month during consecutive years, thus preventing the resource from recovering to its pre-impacted condition. The duration and frequency of adverse salinity exposure impact the survival of the SAV community and associated organisms, as well as productivity, water quality water, and sediment stability in the Everglades–Florida Bay transition zone, unless adequate time is allowed for recovery.
- Review of salinity relationships developed in the report shows that the freshwater flows needed to maintain salinity below 30 psu in the transition zone will also prevent strong negative impacts to downstream SAV and other living resources in northeastern Florida Bay. These flows should sustain a variable estuarine salinity condition, with less than 20 psu during the wet season and less than 40 psu during the dry season in the northeastern Bay.
- During periods when salinity in the transition zone are above 30 psu, salinity downstream in northeastern Florida Bay generally exceed 40 psu and may be considerably higher, representing a losses of estuarine conditions, habitat, productivity, and small forage organisms in this system.

OCCURRENCES OF RESOURCE IMPACTS

A model simulation was conducted to determine how often identified salinity thresholds have been exceeded under historical conditions. This analysis provides insights regarding the magnitude and frequency of environmental variability, causes of this variability (e.g. natural climatic versus water management), and those antecedent conditions that contributed to the current ecological status of this region. Model simulations used best available hydrologic and salinity data, historical operating facilities and procedures, and climate conditions to simulate historical conditions in the transition zone and Florida Bay for the period from 1970-2002. Model results from this simulation were then analyzed to identify periods when monthly average salinity conditions at the Taylor River site would have exceeded 30 psu.

Results based on the 33-year historical model run (1970-2002), indicated that the predicted monthly average salinity at the Taylor River site exceeded 30 psu during 12 years of the simulation period. This threshold was exceeded during two consecutive years during 1970-1971; for three successive years during 1973-1975; and for four successive years during 1989-1992. These periods generally corresponded to times when south Florida was experiencing extended regional droughts and/or onset of the subsequent wet season was delayed, resulting in elevated salinity conditions. This analysis also suggested that with current (post 1980) water management practices in place, some exceedances of the 30 psu salinity threshold in the 1970s may have been avoided.

Loss of *Ruppia* and SAV dependent species likely occurred in the transition zone during periods when monthly average salinity exceeded 30 psu in Taylor River, and likely became more severe as elevated salinity re-occurred during consecutive years. Changes in SAV and macroalgal diversity in northeastern Florida Bay likely occurred during such periods, with decreased *Halodule*, resulting in unstable conditions in the Florida Bay ecosystem, as observed during and after the 1989-1990 drought.

FLOWS AND WATER LEVELS DURING PERIODS WHEN RESOURCE IMPACTS OCCUR

The FATHOM model was used to simulate historic (1970-2002) salinity conditions in Florida Bay and estimate inflow of fresh water to Florida Bay during and prior to periods when average monthly salinity were above 30 psu at the Taylor River site. Periods when elevated monthly average salinity occurred during consecutive years under historical conditions generally corresponded to periods when the total annual inflow across the model boundary that represents input to northeastern Florida Bay was less than 105,000 acre-feet for two successive calendar years. A more detailed analysis of flows indicated that conditions with salinity exceeding 30 psu could occur even during years when the total annual flow to northeastern Florida Bay was greater than 105,000 acre-ft. Such conditions occurred when salinity in Taylor River during the period from January through March were above 19 psu and preceding 3-month total flows to northeastern Florida Bay were less than 7,000 acre-feet.

RECOVERY AND PREVENTION STRATEGIES

These analyses suggest that once the criteria for significant harm have been formally established through the MFL rule development process, a number of steps could potentially be taken by water managers to decrease the occurrences of high salinity conditions (above 30 psu) at the Taylor River site. These actions will be defined in the final rule and technical documentation in terms of recovery strategies (if the MFL criteria are being exceeded under current conditions) or prevention strategies (if the MFL criteria are likely to be exceeded in the future).

As part of a continuing adaptive management program for this region, upstream flows, water levels and salinity at the Taylor River site, SAV and macroalgal resources along the transect, should be continually monitored. Fresh water flows through the transition zone during very dry periods can potentially be managed to reduce or prevent high salinity conditions by providing additional water deliveries to Taylor Slough when sufficient good quality water is available. Future planning efforts and field tests should evaluate the feasibility and/or need for additional regional storage that may be needed to provide these increased flows.

CONCLUSIONS

This document describes the District staff's evaluation of the relationships between the hydrologic conditions of the southern Everglades and resulting ecological status in the salinity transition zone and northeastern Florida Bay. The resulting information can be used in the rule development process for identification of a Florida Bay "Minimum Flow and Level" (MFL) standard. Based on these analyses, the following conclusions are presented and discussed in this report:

- SAV habitat within the Taylor River/Little Madeira Bay/ Eagle Key gradient is representative of conditions in the Everglades–Florida Bay Transition Zone and is an critical feature of the Florida Bay ecosystem.
- Freshwater discharges from the regional water management system have a direct effect on salinity conditions in the transition zone and also influence adjacent waters within northeastern Florida Bay.
- Protection of transition zone and Florida Bay resources can be achieved by providing sufficient freshwater flow, including discharges from regional water management facilities, to maintain monthly average salinity less than 30 psu at the Taylor River monitoring site.
- A minimum annual discharge of 105,000 ac-ft into northeastern Florida Bay, as simulated by the FATHOM Model, is likely to maintain salinity below 30 psu at the Taylor River site. A three-month total flow of 7,000 ac-ft or greater may be needed during exceptionally dry periods (especially when January–March salinity is at or above polyhaline conditions (19 psu).
- These flows should result in salinity conditions that protect widgeon grass (*Ruppia*), SAV and macroalgal habitat, and associated resources along the transition zone gradient and protect seagrass communities and associated biota in northeastern Florida Bay.
- Analyses of reconstructed historic conditions suggest that the 30 psu monthly average salinity threshold is exceeded about once every three years (12 out of 33 years from 1970-2002) and that multi-year exceedances occur about once every six years.

The analyses presented in this report are based on best available information. The need for additional work is recognized. The following list summarizes limitations in the information presented and suggests future work.

- A monitoring program consistent with these recommendations and objectives should be instituted that includes salinity monitoring and periodic sampling of widgeon grass and other transition zone SAV and macroalgae.
- Research on the response *Ruppia* to salinity levels and variability, including effects on seed production, seed bank viability, and reproductive success should be implemented. The dynamic model of Florida Bay SAV should be expanded to include *Ruppia*.
- The habitat value of Ruppia and other SAV or macroalgae of the transition zone should be quantitatively assessed.
- These initial efforts to develop salinity-resource impact relationships for the Taylor River transect and northeastern Florida Bay should be expanded to include a broader area accounting for most coastal inflows to this region of the Bay.
- Additional investigations should be initiated to determine effects of inflows from other coastal basins on salinity and resources in other areas of the Bay, including western Florida Bay, central Florida Bay, and Whitewater Bay.
- The spatial distribution and seasonal timing of inflow to northeastern Florida Bay should be included as elements to be further investigated in the FBFKFS and CERP projects. The proposed salinity and flow criteria should be included as system-wide performance measures and considered in projects and analyses that affect inflows.
- Relationships between water levels at various sites in the Everglades and C-111 basin and Florida Bay salinity (including central, southern, and western regions) should be investigated further. Analysis should include the use of improved

hydrologic and hydrodynamic models that are being built for the FBFKFS (i.e. TIME and EFDC models). Likewise, improved ecological models that may be produced as part of the FBFKFS or other projects should be applied to future analyses.

- The future with CERP project scenarios may result in a reduction in the occurrence of high salinity conditions in Taylor River and northeastern Florida Bay relative to current conditions. Additional analysis of the effects of CERP projects should be addressed by the FBFKFS.
- Any future Florida Bay MFL should be evaluated to ensure consistency with current Everglades MFL criteria. Since these criteria are based on stage, quantitative links need to be established among water levels, flows and salinity.
- As new information and modeling tools are developed or improved and/or modifications are made in the basin, the relationships between freshwater inflow, salinity conditions in the transition zone and northeastern Florida Bay and impacts to biological resources, should be reviewed and revised as needed.

Table of Contents

Document Structure

This report is organized into a framework of six chapters, as follows:

- Chapter 1 serves as an introduction to the document.
- Chapter 2 describes the geographic setting, the resources at risk and the major issues concerning the use and conservation of resources within Florida Bay and its watershed.
- Chapter 3 describes resource functions, considerations and exclusions for Florida Bay.
- Chapter 4 documents the methods used to assess impacts for the different areas, resources and functions, and it describes the results of associated analyses.
- Chapter 5 outlines the specific hydrologic information developed to indicate the degree of resource impact that occurs, and it provides an analysis of the specific relevant factors and implications of salinity-flow relationships. Needs for future monitoring, research and modeling are also described.

Appendices A through J, under separate cover, include technical information such as legal documents related to Minimum Flows and Levels and Florida Bay resources, descriptions and analyses of methods and tools, supplemental data and analyses, and associated literature citations. A report summarizing the peer review panel findings (Appendix K) is attached.

List of Tables

List of Figures

List of Appendices

Appendices A through J, under separate cover, include technical information such as descriptions and analyses of methods and tools, supplemental data and analyses, and associated literature citations. Additional appendices of supplemental information are anticipated as necessary to support this plan through administrative rulemaking, including results of the peer review and related correspondence, laws and rules, and other MFL-related activities in the watershed.

Acronyms and Abbreviations

ac-ft	acre-feet
C&SF Project	Central and Southern Florida Flood Control Project
CERP	Comprehensive Everglades Restoration Plan
cfs	cubic feet per second
CUP	consumptive use permitting
DBHYDRO	South Florida Water Management District's hydrometeorological database
DERM	Miami–Dade County Department of Environmental Resources Management
Df	degrees of freedom (statistical term)
District	South Florida Water Management District
ENP	Everglades National Park
ET	evapotranspiration
F.A.C.	Florida Administrative Code
FATHOM	Flux-Accounting Tidal Hydrology Ocean Model -
FB/FKFS	Florida Bay/Florida Keys Feasibility Study
FDEP	Florida Department of Environmental Protection
FIU	Florida International University
FKNMS	Florida Keys National Marine Sanctuary
F.S.	Florida Statutes
FWC	Florida Fish and Wildlife Conservation Commission
g	gram (s)
g dw	grams dry weight
GUI	graphical user interface
GUIDE	graphical user interface development environment
MAP	Monitoring and Assessment Plan
MFL	Minimum Flow and Level
mgd	million gallons per day
MLLW	mean lower low water

msl	mean sea level
NGVD	National Geodetic Vertical Datum
NSM	Natural System Model
OFW	Outstanding Florida Water
ppt	parts per thousand
psu	practical salinity units
PWS	public water supply
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RECOVER	Restoration Coordination and Verification
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SAV	submersed aquatic vegetation
SDCS	South Dade Conveyance System
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SWIM	Surface Water Improvement and Management
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VEC	valued ecosystem component
WCA	Water Conservation Area
WMD	water management district

CHAPTER 1: INTRODUCTION

BACKGROUND

Florida Bay is a shallow subtropical estuary on the southern coast of Florida in Monroe County (**Figure 1**) bordered on the east by the Florida Keys and on the west by the Gulf of Mexico. The Bay and its watershed are located primarily within the boundaries of Everglades National Park and constitute the state's largest estuarine system, covering approximately 850 square miles (2,200 sq. kilometers). Florida Bay is a priority water body for the development of a Minimum Flow and Level (MFL) norm under Section 373.042(2), Florida Statutes (F.S.). Because it is a large, biologically diverse system influenced primarily by a natural watershed, scientists and resource managers agree that MFLs for the resource should focus largely on those Bay subregions influenced by freshwater inflow derived from the state's managed canal system. Accordingly, the present report documents the methods and technical analyses used by the South Florida Water Management District (SFWMD or District) to develop MFLs for the northeastern section of Florida Bay, which is influenced primarily by freshwater flows from the regional canal system into Taylor Slough (**Figure 1**).

The MFLs for Florida Bay are being developed pursuant to the requirements contained within the "Florida Water Resources Act," specifically Sections 373.042 and 373.0421, F.S., as part of a comprehensive water resources management approach intended to ensure the sustainability of water resources. The proposed MFLs are not a "stand-alone" resource protection tool but should be considered in conjunction with all other resource protection responsibilities granted to the water management districts by law, such as consumptive use permitting, environmental resource permitting, water shortage management and water reservations. A model framework identifying the relationships among these tools was used in MFL development and is discussed in the present document. Pursuant to Chapter 373.0361 F.S., the District has completed regional water supply plans that include recommendations for establishment of MFLs and strategies for recovery and prevention. In addition, achievement of the required flows and water levels is a long-term component of the Comprehensive Everglades Restoration Plan (CERP). Establishment of MFLs alone is not intended to be sufficient in itself to maintain a sustainable resource or to protect it from significant damages during the broad range of water conditions occurring in the managed system. Setting a minimum flow is viewed more as a starting point to define water needs for preventing significant harm. The necessary hydrologic regime for restoration of the Florida Bay ecosystem must be defined and implemented also through regional water supply plans, the use of water reservations, and other water resource protection tools that will ultimately define the water needs to sustain a healthy ecosystem.

As the first formal step in establishing MFLs for Florida Bay, the present report presents the scientific and technical framework for determining MFLs based upon the best available information (an approach applicable as well to other surface water and groundwater within the District). The report also describes the development of a methodology and technical information through use of relevant supporting data and analyses. The draft document is to undergo independent scientific peer review pursuant to Section 373.042, F.S., and rule development workshops are to be held to discuss MFL-related concepts for the Bay.

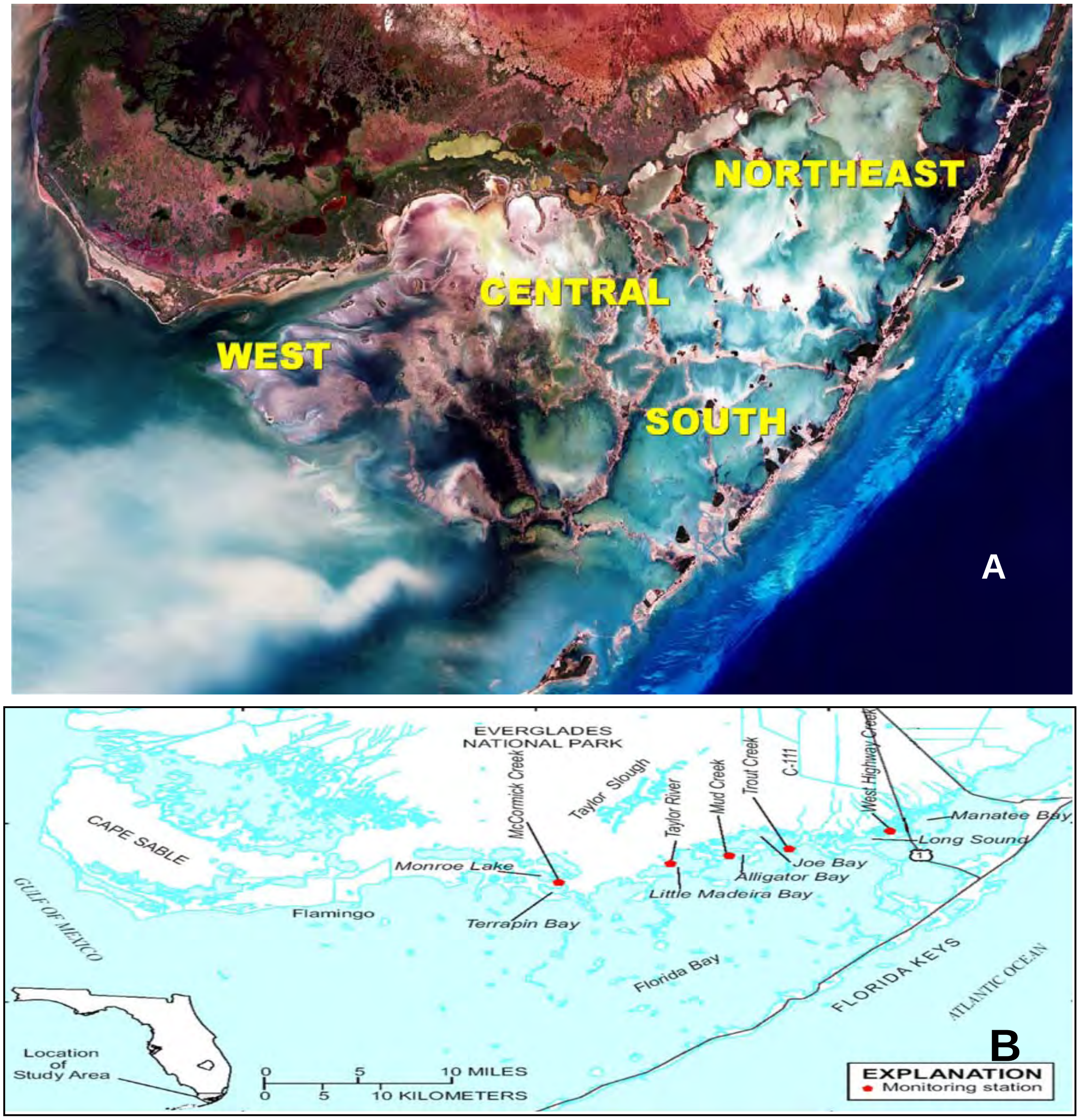


Figure 1. Location and Major Features of Florida Bay. Top (A): LANDSTAT-7 extended thematic mapper image showing its shallow-bank bathymetry and principal subregions (Florida Bay Science Program 2003). Bottom (B): Location of gauged inflow to northeastern and central Florida Bay (from Hittle et al. 2000).

PROCESS AND BASES FOR ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS

Process Steps and Activities

The process for establishing a minimum flow for the northeastern subregion of Florida Bay is as follows:

- Develop a methodology and technical basis for MFL criteria.
- Draft an MFL technical document.
- Conduct scientific peer review of the technical document pursuant to Section 373.0421, F.S.
- Revise the report as recommended by the peer review panel; submit report to the peer review panel again and to the public and appropriate agencies for additional comments; and incorporate revisions into final report.
- Conduct rule development workshops, including development of potential criteria.
- Present a recommended rule to the District's Governing Board for adoption.

Legal and Policy Bases for Establishment of Minimum Flows and Levels

Section 373.042(1), F.S., requires that the water management districts establish MFLs for surface waters and aquifers within their jurisdiction. According to this statute, the minimum flow is defined as the "…limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.…" The statute further directs water management districts to use the best available information in establishing MFLs. Each water management district must also consider, and at its discretion may provide for, the protection of non-consumptive uses in the establishment of MFLs. In addition, a baseline condition for the protected resource functions must be identified through consideration of changes and of structural alterations in the hydrologic system.

The following sections outline the legal and policy factors (Appendix A) relevant to establishing MFLs under Florida Statutes. In summary, the following questions are addressed:

- What are the priority functions of each water resource, and what is the baseline condition for the functions being protected?
- What level of protection for these functions is provided by the MFL significant harm standard?

Relevant Water Resource Functions

Each surface water body or aquifer serves an array of water resource functions that must be considered as input factors for the definition of the basic concept of significant harm when setting an MFL. The term "water resource" is used throughout Chapter 373, F.S. Water resource functions protected under this statute are broad and varied, as illustrated in Section 373.016, F.S., and include flood control, water quality protection, water supply and storage, navigation, recreation and fish and wildlife protection. In turn, the State Water Resource Implementation Rule, Section 62-40.405, Florida Administrative Code (F.A.C.), outlines specific factors to consider, including protection of natural seasonal changes in water flows or levels, water levels in aquifer systems and environmental values associated with aquatic and wetland ecology. Other specific considerations include the following:

- Fish and wildlife habitat and the passage of fish.
- Maintenance of supply and storage of fresh water.
- Water quality.
- Estuarine resources.
- Transfer of detrital material.
- Filtration and absorption of nutrients and pollutants.
- Sediment loads.
- Recreation in and on the water.
- Navigation.
- Aesthetic and scenic attributes.

The District's Governing Board determines which resource functions to consider in establishing MFLs—an analysis requiring a comprehensive assessment of the sustainability of the resource itself as well as of the resource's role in sustaining overall regional water resources. Chapter 3 of the present document describes in detail the relevant water resource functions of the Florida Bay.

Considerations and Exclusions: Baseline Conditions to Protect Water Resource Functions

Once the water resource functions to be protected by a specific MFL have been defined, the baseline resource conditions for assessing significant harm must be identified. Considerations for making this determination are set forth in Section 373.0421(1)(a), F.S., which requires that the water management districts, when setting an MFL, consider changes and structural alterations that have occurred to a water resource. Likewise, Section 373.0421(1)(b), F.S., recognizes that certain water bodies no longer serve their historical function and that recovery of these water bodies to historical conditions may not be feasible. These provisions are discussed in Chapter 3, examining their applicability to the minimum flows proposed for Florida Bay.

This consideration is one of the most complex policy driven portions of the MFL development for the Governing Board. It potentially includes balancing of economic feasibility and impacts of removing or otherwise addressing existing changes or structural constraints currently in the system. These constraints have developed over time through a series of public policy decisions that if reversed could have far reaching implications, such as removal of roads or bridges, reduction of public water supplies, or flood impacts. The evaluation conducted herein does not address this eventual policy determination by the Governing Board. This evaluation identifies the flow and salinity relationships and the water resource implications of managing the hydrology under various conditions.

Level of Protection for Water Resource Functions Provided by the MFL Standard of *Significant Harm*

The overall purpose of the Florida Water Resources Act (Chapter 373, F.S.) is to ensure the sustainability of water resources of the state (Section 373.016, F.S.). To carry out this responsibility, Chapter 373 provides the District with several tools with varying levels of resource protection standards. MFLs are a part of this framework. The role of MFLs, the protection that MFLs offer, and the similarity and differences between MFLs and other water resource tools available to the District are important concepts. The scope and context of MFL protection revolve around the goal of preventing significant harm. The following discussion provides some context to the MFLs statute, including the significant harm standard, vis-à-vis other water resource protection statutes.

Resource sustainability is the overarching objective of all water resource protection standards (Section 373.016, F.S.) and tools. Each water resource protection standard must fit into a statutory niche to achieve this overall goal. A few of the many available resource protection tools are the reservation of water for fish and wildlife or for health and safety purposes (Section 373.223[3], F.S.) and the use of aquifer zoning to prevent undesirable uses of the groundwater (Section 373.036[4]–[5], F.S.). Interacting with these and other water resource protection standards and tools is the idea of three distinct levels of possible harm to the resources—harm, significant harm and serious harm—which are relative resource protection terms, each playing its role in the ultimate goal of achieving a sustainable water resource. For instance, pursuant to Parts II and IV of Chapter 373, surface water management and consumptive use permitting regulatory programs and tools must prevent harm to the water resource. And water shortage statutes dictate that in order to prevent serious harm to the water resources, permitted water supplies must be restricted from use at times (perhaps by applying the tool of water shortage declaration). In between harm and serious harm, MFLs are set at the point at which significant harm to the water resources or to the ecology would occur if appropriate tools were not applied. The SFWMD has proposed that the conceptual relationship among the various levels of harm be represented as depicted in **Figure 2.**

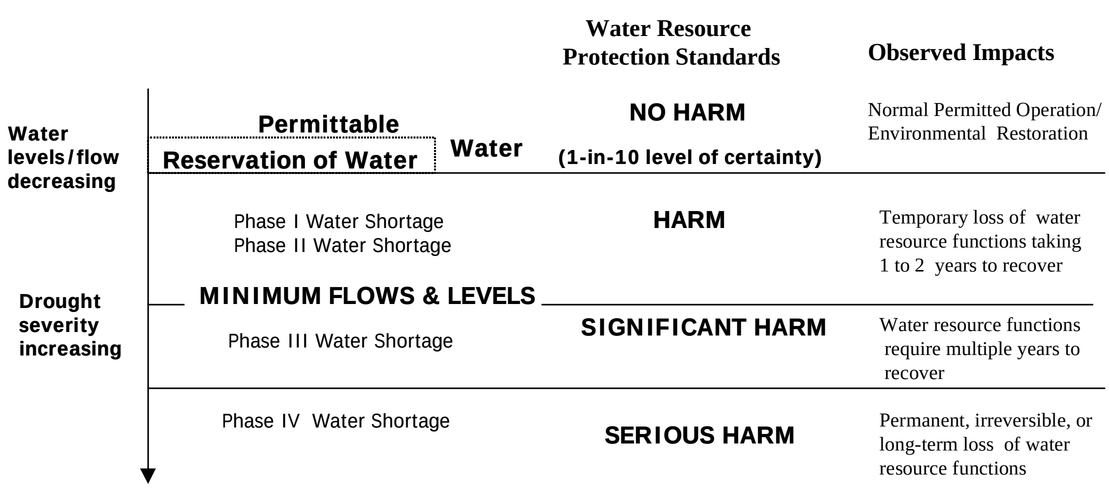


Figure 2. Conceptual Relationships among the Terms Harm, Significant Harm and Serious Harm.

The general narrative definition of significant harm proposed by the SFWMD (Chapter 40E-8.021[28], F.A.C.) for the water resources of an area is as follows:

> Significant Harm means the temporary loss of water resource functions, which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm. The specific water resource functions addressed by a MFL and the duration of the recovery period associated with significant harm are defined for each priority water body based on the MFL technical support document.

The specific technical analysis under review focuses on relatively low flow and high salinity conditions and attempts to identify thresholds of salinity exposure that impact ecological structure or function of valued ecosystem components such that recovery of these attributes is likely to span at least two years. The requirement that the level of resource impact associated with significant harm take more than two years to recover is a guide only, and is intended to indicate that "significant harm" is not an impact level that occurs under average or natural hydrologic conditions. Instead, "significant harm" refers to effects that occur during dry hydrologic conditions at a level and frequency as a result of man-made withdrawals that cause increasingly severe, cumulative effects on water resources, e.g. if an exceedance of the threshold condition reoccurs within an interval that is shorter than the time needed for that resource to recover.

Other Levels of *Harm* Considered in Florida Statutes

In order to give context to the proposed significant harm standard, a discussion is provided below regarding the two other levels of harm—as applied in the conceptual model for consumptive use permitting (harm) and in the conceptual model for the declaration of a water shortage (serious harm).

Harm Standard in the Consumptive Use Permitting Role

The resource protection criteria used for consumptive use permitting (CUP) are based on the level of impact considered as causing harm to the water resource. These criteria are applied to various resource functions to establish the range of hydrologic change that can occur without harm. The hydrologic criteria include components of level, duration and frequency and are used to define the amount of water that can be allocated from the resource. Together, the criteria on saltwater intrusion, wetland drawdown, aquifer mining and pollution prevention in Chapter 40E-2, F.A.C., define the harm standard for purposes of consumptive use allocation. These harm criteria are applied using climatic conditions that represent an assumed level of certainty. The 1-in-10 year drought level of certainty is also the water supply planning goal that was established in Section 373.0361, F.S. The standard for harm used in the CUP process is considered as the point at which adverse impacts to water resources can be restored within a period of one to two years of average rainfall conditions. These short-term adverse impacts are addressed for the CUP program, which calculates allocations to meet demands for use during relatively mild dry season events, defined as the 1-in-10 year drought.

Serious Harm Standard in the Water Shortage Declaration Role

Pursuant to Section 373.246, F.S., water shortage declarations are designed to prevent serious harm from occurring to water resources. Serious harm, the ultimate harm to the water resources as contemplated under Chapter 373, F.S., can be interpreted as long-term, irreversible or permanent impacts to the water resource. Declaration of water shortages is the tool used by the Governing Board to prevent serious harm—impacts such as those experienced in drought events more severe than the 1-in-10 level of drought used in the CUP criteria.

When drought conditions exist, water users increase withdrawals to supplement water not provided by rainfall, typically for irrigation or outdoor use. In general, the more severe the drought, the more supplemental water is needed. These increased withdrawals increase the potential for serious harm to the water resource because of decreased rainwater input into the resource combined with increased demand by users. Thus, the SFWMD has implemented its water shortage authority to restrict consumptive uses by applying the concept of equitable distribution between users and the water resources themselves (Chapter 40E-21, F.A.C.).

Under this program, different levels or phases of water shortage restrictions are imposed relative to the severity of drought conditions. The four phases of the current water shortage restrictions are based on relative levels of risk posed to resource conditions leading up to serious harm impacts. Under the SFWMD's program, Phase I and Phase II water use restrictions include conservation techniques and restrictions on minor uses such as car washing and lawn watering, designed primarily to prevent such outcomes as localized recoverable damage to wetlands or short-term inability to maintain water levels needed for restoration. In turn, Phases III and IV require more rigorous usage cutbacks associated with some level of economic impact to users, such as restrictions on agricultural irrigation.

MFL RECOVERY AND PREVENTION STRATEGY

The District's MFLs are implemented through a multifaceted recovery and prevention strategy designed pursuant to Section 373.0421(2), F.S. An MFL recovery and prevention strategy will be developed and will be included in the present document prior to administrative rulemaking. Section 373.0421(2), F.S., provides that if it is determined that water flows or levels are presently below the MFL standard or that they will fall below an established MFL standard within the next 20 years, the water management district must develop and implement a recovery or prevention strategy, whichever would apply. The 20-year period should coincide with the regional water supply plan horizon for the area, and the strategy is to be developed in concert with that planning process.

The general goal of the recovery and prevention strategy is to take actions to achieve the MFL criteria while continuing to provide sufficient water supplies for all reasonable-beneficial demands (reasonable-beneficial uses entail water use in such quantity as is necessary for economic and efficient utilization for a purpose and in a manner both reasonable and consistent with the public interest). If the existing condition of the resource is below the MFL, then recovery to the MFL must be achieved "as soon as practicable." A water management district's ability to implement proposed actions punctually is influenced by many different factors, including funding availability, detailed design development, permittability of regulated actions, land acquisition and the implementation of updated permitting rules.

From a regulatory standpoint, depending on the existing and projected flows or levels, either water shortage declaration triggers or interim consumptive use permit criteria, or both, may be recommended in the recovery and prevention strategy. The approach varies depending on whether the MFL criteria are currently exceeded and on the specific cause of the MFL exceedance—e.g., consumptive use withdrawals, poor surface water conveyance facilities or operations, over drainage or a combination of these factors.

Incremental measures to achieve the MFL must be included in the recovery and prevention strategy, along with a timetable for the provision of water supplies necessary to meet reasonable-beneficial uses. Such measures include conservation and other efficiency procedures and the development of additional water supplies. In accordance with Chapter 373, F.S., these measures must make water available "concurrent with, to the extent practical, and to offset reductions in permitted withdrawals, consistent with the provisions of this chapter." The determination of what is "practical" in identifying measures for concurrently replacing water supplies will most likely be made through consideration of economic and technical feasibility of the potential options available.

CHAPTER 2: DESCRIPTION OF THE WATER BODY

INTRODUCTION

Florida Bay is a large triangular tropical lagoon/bay located immediately south of the Florida peninsula and the Everglades. It is bounded on the west by the Gulf of Mexico and on the south and east by the Florida Keys and Atlantic Ocean. Some 82 percent of the Bay is located within the boundaries of the Everglades National Park, and much of the remaining area is located within the Florida Keys National Marine Sanctuary. With an area of approximately 850 square miles (2,200 sq. kilometers), Florida Bay is the state's largest estuary system. The Bay is relatively shallow, with an average depth of less than one meter, and it includes more than 200 small islands or "keys," many of which are rimmed with mangroves and contain "flats" dominated by calcareous algal mats (CROGEE 2002). Florida Bay is generally divided into six zones: the northern transition zone; the eastern, central and western zones; and the Atlantic and Gulf of Mexico transition zones (NOAA 2000). In Chapter 4, for this MFL study, an "Everglades-Florida Bay salinity transition zone" is identified within northeastern Florida Bay (**Figure 3**).

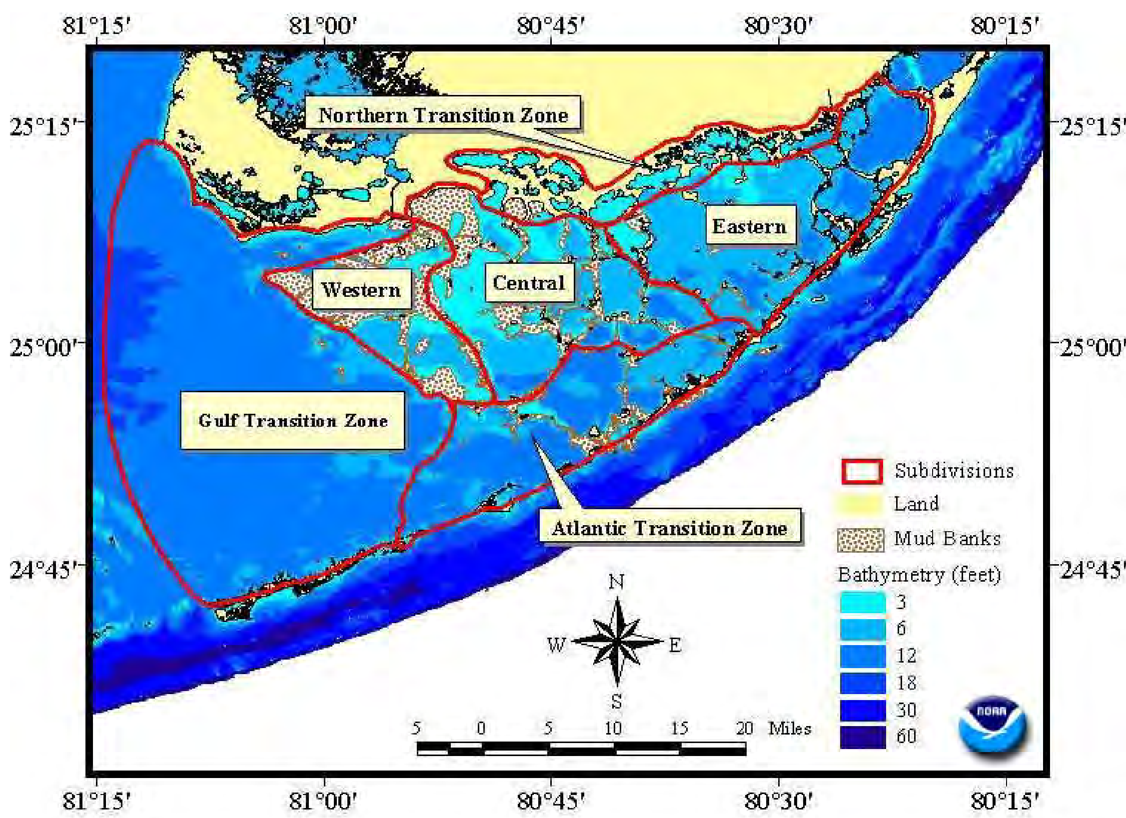


Figure 3. Florida Bay Zones (NOAA 2000).

One key feature of Florida Bay consists of numerous shallow carbonate mud banks dividing the Bay into semi-isolated basins, restricting circulation among these basins and attenuating currents and tidal ranges, especially in the central and eastern portions of the Bay. Because of these patterns of restricted water circulation and the lack of surface water inflows, the western and central Bay areas commonly experience hypersaline conditions (salinity greater than that of seawater) during the dry season.

Salinity levels within the Bay are driven primarily by 1) direct rainfall and evapotranspiration, 2) overland sheet flow from marl-forming wetlands in the C-111 basin and in Taylor Slough feeding some 20 small creeks that drain into central and northeastern Florida Bay and 3) indirect inflows from Shark River Slough that mix with waters from the Florida Shelf and the Gulf of Mexico across Florida Bay's open western boundary, especially during wet periods.

At least 22 commercially and/or recreationally important aquatic species are known to use Florida Bay as a nursery ground (McIvor et al. 1994). A guide boat industry in the Florida Keys operates within Florida Bay, targeting snook, tarpon, permit (pompano), bonefish, spotted sea trout and mangrove snapper. Florida Bay is known as the principal inshore nursery for the offshore Tortugas pink shrimp; the Bay also provides critical habitat for juvenile spiny lobsters and stone crabs and supports numerous protected species, including the bottle-nosed dolphin, the American crocodile, the West Indian manatee and several species of sea turtles.

During the summer of 1987, approximately 100,000 acres of seagrass (primarily Thalassia testudinum) "died off" in western Florida Bay. This die-off was followed by phytoplankton blooms and sponge die-offs. Following the seagrass die-off, the Bay also experienced water clarity reductions, micro-algal blooms of increasing intensity and duration and population reductions of economically significant species such as pink shrimp, sponges, lobster and recreational game fish (Robblee et al. 1991a, Boesch et al. 1993, Fourqurean and Robblee 1999, Hall et al. 1999). In addition to these problems, the diversion of water away from Taylor Slough and Shark River Slough for flood control and urban water supply has modified the salinity regime of Florida Bay. These changes have been implicated in the reduced recruitment of pink shrimp, snook and redfish, shifts in the distribution of the American crocodile and manatees and reductions in populations of wading birds, forage fish and juveniles of game fish species (McIvor et al. 1994). Accounts by longtime residents and fishermen also suggest that populations of all the living resources in and around the estuarine waters of south Florida were more abundant and diverse in years past than they are today, although the system has probably always experienced wide fluctuations in productivity (DeMaria ,1996)

Recognizing these observed ecological changes, the state of Florida and the federal government made a commitment to improve environmental management in order to restore the Bay toward a more natural state. A collaborative interagency research program was initiated in 1994 to efficiently document the history of the Bay, monitor its status and trends, understand human impacts on the Bay and provide a scientific basis for restoration. With partners from other state and federal agencies and from the academic community, the District has initiated a comprehensive investigation of the Bay and its upstream watershed in order to understand better the ecological consequences of alternative environmental management actions (Florida Bay Program Management Committee, 2004).

MAJOR HYDROLOGIC UNITS OF FLORIDA BAY AND ADJACENT COASTAL AREAS

Southern Everglades

The term "southern Everglades" refers primarily to the wetlands, sloughs, tree islands and marl-forming wet prairies located within Everglades National Park (ENP). Covering nearly 1.5 million acres, ENP is the largest remaining subtropical wilderness in the United States (**Figure 4**).

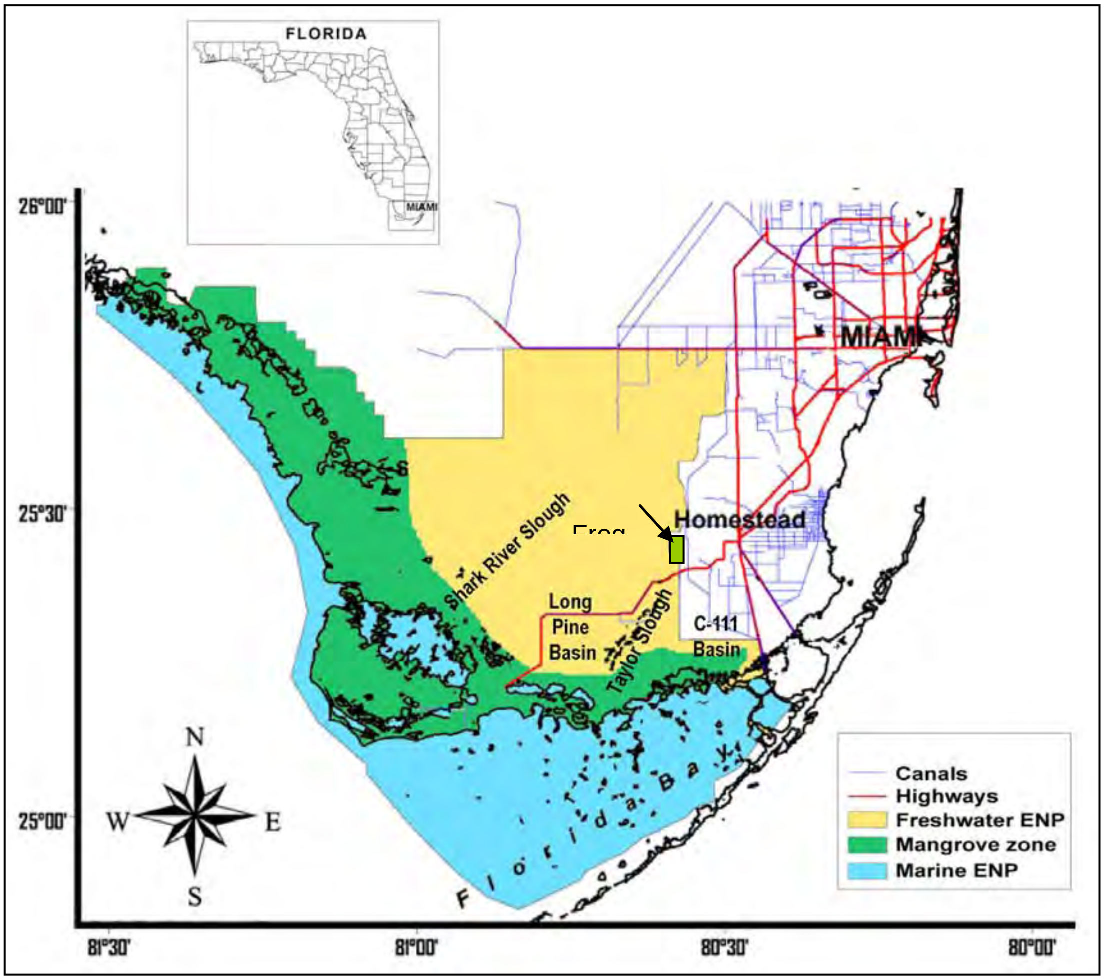


Figure 4. C-111 Basin, Taylor Slough Basin, Long Pine Basin, Shark River Slough Basin and Boundaries of Everglades National Park (ENP).

The ENP was the first national park established to preserve purely biological resources—to protect the unique and primitive natural conditions of the subtropical Everglades. Today the ENP protects the largest continuous stand of sawgrass prairie in North America, the most significant breeding ground for tropical wading birds in North America, the largest mangrove forest in the Western Hemisphere and a nationally significant estuarine system in Florida Bay. The park's aquatic environment is dependent on seasonal rainfall and overland sheet flow of water from the north. In the southern Everglades region, four basins provide freshwater flows to Florida Bay. Taylor Slough and the C-111 basin located within the southeast portion of ENP are the main sources of freshwater flow for eastern and central Florida Bay, Local runoff and groundwater from

Long Pine Basin flows into central Florida Bay, while Shark River Slough (SRS) is the main source of surface water inflow for Whitewater Bay and may influence salinity levels within western Florida Bay during extreme wet periods (**Figure 4**). Let us consider each of these basins in turn, east to west.

C-111 Canal Basin

The C-111 Canal is part of the South Dade portion of the Central and Southern Florida (C&SF) Project authorized in 1962. The C-111 basin includes about 100 square miles of agricultural land located within southern Miami-Dade County (Homestead/Florida City area). Historically, a portion of the C-111 basin included the headwaters of Taylor Slough (**Figure 4**).

The C-111 basin comprises five primary main canals—namely, C-111, C-111E, C-113, the L-31N Borrow Canal and the L-31 W Borrow Canal (**Figure 5**). These canals have three functions: 1) to provide drainage and flood protection for developed lands located east of the C-111 Canal, 2) to provide water supply water for the C-111, C-102 and C-103 basins and to Taylor Slough and the panhandle area of ENP and 3) to maintain groundwater elevations in the lower reach of the C-111 Canal in order to prevent saltwater intrusion into the local groundwater table.

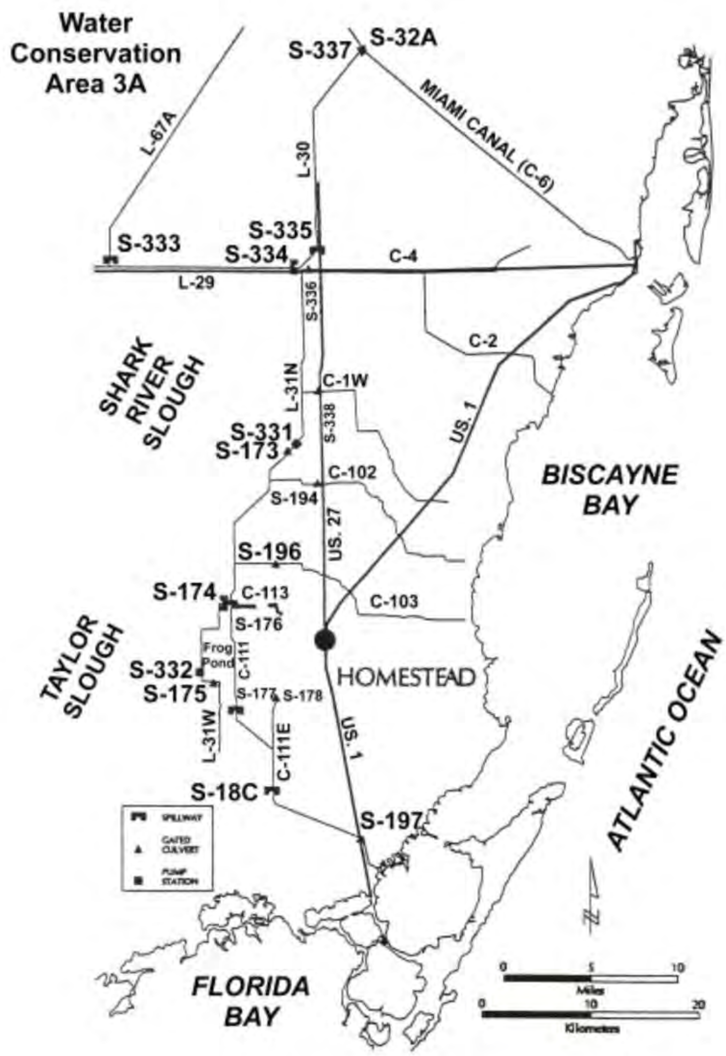
Because of the extreme porosity of the underlying Biscayne Aquifer, water levels in C-111 Canal have a direct impact on water levels in adjacent ENP wetlands and in agricultural lands east of the canal. Restoration efforts are underway in the C-111 basin to improve the hydroperiod in Taylor Slough and the volume and timing of water deliveries to ENP and Florida Bay. Existing flood protection will be maintained for developed lands east of canals L-31N and C-111.

Water is supplied to the C-111 basin by the South Dade Conveyance System (SDCS) by way of the L-31N Borrow Canal. Actually, the C-111 Canal represents the final segment of the South Dade Conveyance System. At times the C-111 Canal also receives water from Water Conservation Area 3 (WCA 3) and seepage from Shark River Slough and the headwaters of Taylor Slough from the L-31N Canal through S-176. The L-31W Borrow Canal is used to make water deliveries to Taylor Slough in ENP (by way of the S-332D, S-332 and S-175 structures). Water is discharged to the panhandle area of the ENP by way of overbank flow along the south side of the C-111 Canal (between S-18C and S-197). The C-111 Canal and the S-18C structure were completed in 1966. At the current location of S-197, an earthen plug was completed in 1970 to prevent saltwater intrusion; this plug was later replaced by 13 operable culverts, all of which are opened during flood conditions to allow a gravity outlet for stormwater in order to provide flood protection for developed portions of the basin. Several structures are utilized to control flow in the basin (including S-174, S-175, S-332, S-176, S-177, S-18C and S-197) (**Figure 5**). During periods of high flow, these waters discharge to the ENP panhandle area, Florida Bay, Manatee Bay and Barnes Sound via S-197.

Taylor Slough Basin

Taylor Slough is the second-largest drainage basin located within ENP (the largest being Shark River Slough). The Taylor Slough basin is a freshwater wetland system encompassing 158 square miles and extending about 20 miles south from the Frog Pond area to the coastal mangrove fringe of Florida Bay (**Figure 4**). This slough occupies a broad depression in the Miami oolite bedrock; the center of that broad depression contains peat up to 2 meters deep, but marl is the slough’s predominant soil overall. Marl soils (calcitic muds) are formed by the precipitation of calcite by cyanobacteria present within these wetlands under shallow-water conditions (Browder et al. 1994). Vegetation in this region of ENP is characterized by a complex of willow-sawgrass marshes, evergreen shrub islands and open sparse rush marshes. To the northeast and east of Taylor Slough, land use is primarily agricultural.

The headwaters of Taylor Slough are in the Rocky Glades, a transitional wetland located within the eastern portion of ENP and hydrologically separating Taylor Slough from Shark River Slough. Historically Taylor Slough has been an important source of fresh water for northeastern Florida Bay (Van Lent et al. 1993). Based on output of the South Florida Water Management Model (version 5.4) for a 36-year period of record, Taylor Slough currently contributes an average of about 243,000 acre-feet of overland sheet flow per year to northern Florida Bay.



The South Dade Conveyance System.

Figure 5. C-111 Canal and South Dade Conveyance System (Light and Dineen 1994).

Prior to the 1960s, wet season water levels in the Rocky Glades and Taylor Slough headwaters were maintained 1.5 to 2.5 ft. higher than today (Johnson and Fennema 1989). These data suggest that higher water levels kept the northern Taylor Slough marshes inundated for 2 to 3 months each year, thereby establishing a hydraulic gradient that sustained surface water and ground water flows to Florida Bay. These higher water levels also retained much of the local wet season rainfall in the wetlands and underlying aquifer, which allowed fresh water to be released gradually, thus tempering salinity fluctuations in the nearshore coastal areas of Florida Bay (Johnson and Fennema 1989).

Beginning in the 1960s, construction of a number of C&SF Project features in southwestern Miami-Dade County led to drainage and diversion of flows away from Taylor Slough into the lower C-111 basin. The building of the C-111 Canal and its associated structures has significantly altered both the volume and timing of freshwater flows delivered from Taylor Slough to Florida Bay. As currently operated, the C-111 Canal shunts a large portion of fresh water away from Taylor Slough, discharging it to the east via the C-111 Canal through which it is delivered to Long Sound (located in Northeast Florida Bay) or to lower Biscayne Bay (via S-197) and the Atlantic Ocean during events of high flow. These hydrologic changes are thought to have been an important contributor to the problem of hypersaline conditions in the nearshore embayments of central and northeastern Florida Bay (Johnson et al., 1988).

Long Pine Basin

That portion of the southern slope north of the coastal swamps and lagoons, and west of Taylor Slough is referred to as the Long Pine Basin (**Figure 4**). The northern boundary includes Long Pine Key and the Everglades Keys. To the west, the area is bounded by State Road 27 (Anhinga Trail). The elevated limestone ridges that run west/southwest from the upper Taylor Slough (Long Pine Key and the Everglades Keys) form a barrier inhibiting sheet flow from Shark River and the lower Rocky Glades. As such they represent the northern boundary of the drainage basin from which surface waters flow south, either into Taylor Slough or directly into Florida Bay. The Park Highway is chosen as the western boundary of this province though some surface drainage does occur, especially in the wet season, through culverts underneath the road.

South of the Everglades Keys, this segment is largely dominated by muhly grass prairies. Almost directly in the middle of the area is a large oblong area of scattered dwarf cypress, known as "hatrack" cypress. Although most of the segment is clearly dominated by natural communities, a significant area of former agricultural lands is also present on the southeastern fringe of Long Pine Key. This area is referred to as the Hole-in- the-Donut.

To the west of Taylor Slough, the southern portion of the Long Pine Basin includes two physiographic provinces (Puri and Vernon 1964), aside from the southern slope. The first of these is the gulf coastal lagoons, which refers to the series of lagoons from Seven Palm Lake to West Lake. A broad continuous strip of land covered by coastal prairie occupies the area north of these lagoons, running southeast to the mangroves bordering Madeira Bay. The northern border of the gulf coastal lagoons roughly corresponds to a partial barrier between fresh and saline waters known as the Buttonwood Embankment (Craighead 1971). A distinct band of pioneer red mangrove (*Rhizophora mangle*) occurs 3 to 8 km (2 to 5 mi) inland of this barrier.

The second province distinguished by Puri and Vernon (1964) in this region is the reticulate coastal swamps which correspond to the more saline black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*) communities which occupy the area south of the Gulf coastal lagoons to Florida Bay.

To the west of lower Taylor Slough the coastal swamps and lagoons are characterized by a series of lakes (or lagoons) fringed by mangroves and some tropical hardwoods toward the eastern end. South of these lagoons toward Florida Bay the area is dominated by buttonwood, and red, black, and white mangroves, and prairies of salt tolerant (halophytic) herbaceous vegetation (Russell et al. 1980).

In contrast to the Taylor Slough and C111 wetland sub-basins, discharge from the Long Pine sub-basin is primarily the result of rainfall in excess of evapotranspiration in the sub-basin; no large tributary surface flows occur into or out of the sub-basin. The Everglades Park Road controls flow across the north and west sides of this sub-basin, and the flow that occurs through the culverts in the road is minor.

Flow in McCormick Creek, the major identified surface water discharge directly out of Long Pine sub-basin, occurs only intermittently. Additionally, the nature of the hydrologic connection between the sub-basin and areas north and west of the Park Road is poorly understood.

A number of culverts allow the exchange of surface water across the Park Road that bounds the Long Pine sub-basin on the north and the west. Flow in these culverts is not monitored continuously, but various measurements have been made over a number of years. Tillis (2001) and Stewart et al. (2002) reviewed these measurements. In general, the average direction of surface flow across the Park Road is directed out of the sub-basin. *Based on this information, it is assumed that excess rainfall from one third of the Long Pine sub-basin discharges north and west through the culverts under the Park Road.*

The Buttonwood Embankment impedes the discharge of surface water directly out of the Long Pine sub-basin south into the central region of Florida Bay. Lorenz (2000) and Holmes et al. (no date) describe this geomorphic feature and trace its influence on the hydrology of Florida Bay and the coastal mangroves in this area. The embankment extends east as far as Joe Bay, and thus also restricts the southward discharge of surface water out of the Taylor Slough sub-basin.

The influence of the Buttonwood Embankment on discharge from the Long Pine and Taylor Slough sub-basin is evident when the USGS creek flow data for the creeks that breach the embankment, i.e. McCormick Creek, Mud Creek and Taylor River, are analyzed. The results indicate that wetland water levels must exceed a threshold of between 1.0 and 2.0 feet before discharge occurs.

Shark River Slough Basin

Shark River Slough is the largest drainage basin in Everglades National Park, but does not discharge directly into Florida Bay. Shark River Slough consists of a broad arc of continuous wetland, dotted throughout with numerous tree islands (**Figure 4**). The slough occupies the center of the Everglades trough, a wide shallow depression in the underlying limestone (White 1970). This natural wetland depression contains organic sediments made up of both shallow and deep peat. The headwaters of Shark River Slough are to the northeast in the area known today as Water Conservation Area 3B (WCA 3B). Historically, water flowed from Lake Okeechobee and surrounding areas in a southeastwardly arc that swept through the extreme northeast section of today's ENP and curved back to the west to flow down the main channel of the slough through Shark River Valley.

This broad, shallow "river of grass" supported a vast range of wildlife and wetland plant communities and habitats. Shark River Slough is the primary source today of freshwater inflow into ENP. Flows from Shark River Slough are discharged into the Gulf of Mexico via various rivers (such as the Shark, Harney and Broad rivers, which flow into Whitewater Bay and the Ten Thousand Islands and ultimately mix with waters of the Gulf of Mexico and the Florida Shelf. During wet periods these flows have the potential to influence salinity patterns across the western boundary of Florida Bay. South Florida Water Management Model data indicate that Shark River Slough contributes an annual average of about 677,000 acre-feet of overland sheet flow to Whitewater Bay and the Gulf of Mexico (SFWMD 2000).

As a result of the construction of major canal systems and roads (such as the Tamiami Trail) and the impoundment of waters into the water conservation areas to the north, much of this water formerly inflowing into ENP, Whitewater Bay and the Ten Thousand Islands area from the Shark River Slough is now absent, having either been retained upstream or diverted away from Shark Slough altogether. The reduction in flow and the changes in water quality throughout the Shark River system have been linked to major effects on the Everglades freshwater marshes and associated coastal ecosystems (Ogden and Davis 1994, USACE 1999). Reduction in freshwater flow and changes in distribution of flows between Shark River Slough and Taylor Slough may have shifted the balance of fresh water to salt water in Florida Bay coastal areas, resulting, among other things, in an accelerated rate of migration of mangroves into freshwater marshes (Ross et al., 2000).

Northern Transition Zone

The eastern portion of the Northern Transition Zone of Florida Bay (**Figure 6**) receives freshwater inputs from the Taylor Slough/C-111 basins. These waters move slowly in the form of sheet flow across marl-forming sawgrass wetlands and through mangrove forests and saline marshes, eventually discharging into 20 mangrove-lined creeks that empty into Long Sound, Joe Bay, Little Madeira Bay, Madeira Bay and Terrapin Bay. Hydrologic conditions in this area are influenced by sheet flow and seepage of fresh water from the Everglades and by the intrusion of Florida Bay water driven by wind and, to a lesser degree, by astronomical tides.

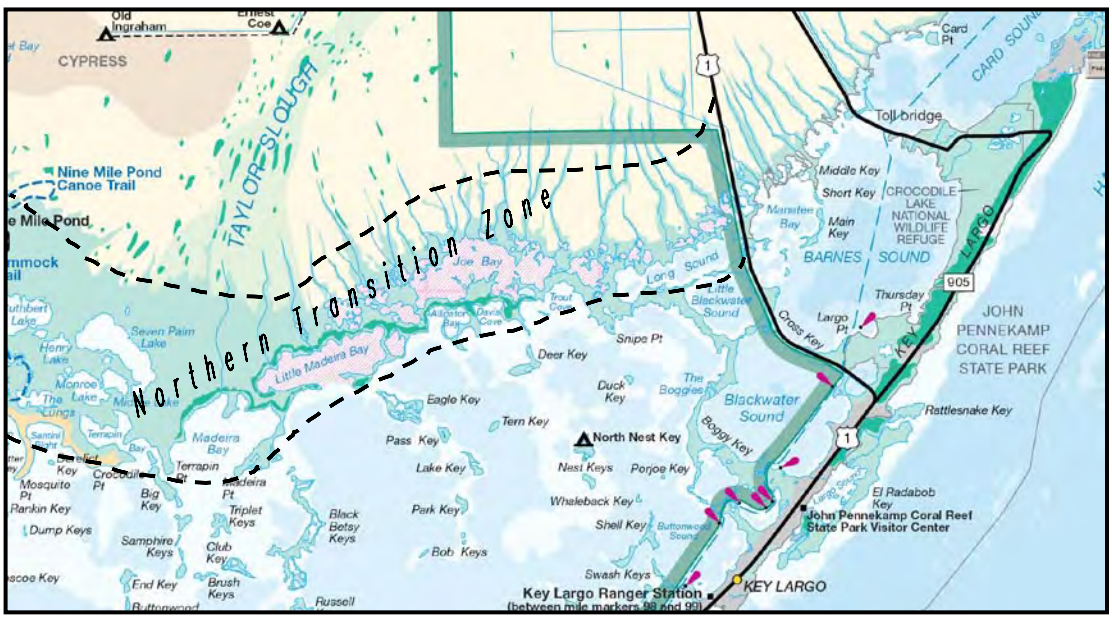


Figure 6. Detail of the Eastern Portion of the Northern Transition Zone Showing Coastal Bays that Receive Water from Taylor Slough.

The northern transition zone is an ecotone (transition area between two adjacent ecological communities) characterized by a gradual vegetation change from marl-forming sawgrass wetlands in the northern reaches, becoming interspersed farther south with dwarf red mangroves trees, which eventually transition into the more salt-tolerant buttonwood trees and white, black and red mangrove trees that grow in the shallow water along Florida Bay's shoreline. Mangroves and their leaf litter produce a significant portion of the essential nutrients that support organisms populating the low end of the estuarine food chain. Mangroves also stabilize the shoreline and help prevent erosion, and over time they can produce land. The mangrove forest floor and root complex are home to a variety of animals, including several threatened and/or endangered species. Many wading birds and shore birds roost or nest within the mangrove canopy.

The northern transition zone is a major component of the greater Everglades ecosystem, with ecological links to both the freshwater Everglades and Florida Bay, and it is a focus of the Comprehensive Everglades Restoration Plan (Davis et al. 2005). In particular, this zone historically supported large wading bird and water fowl populations by providing a food base in the ponds and marshes while making available good rookeries nearby in the forests. These wading bird and water fowl populations greatly diminished in the last century, probably in association with the hydrologic alteration of the Everglades and the salinity increases in the transition zone (McIvor et al. 1994, Davis et al. 2005), but this zone still supports critical avian populations, including wood storks (an endangered species) and roseate spoonbills (a Florida species of special concern). This zone is also of special importance because it is the home of most of the nation's remaining American crocodiles (an endangered species) (Mazzotti 1999).

The transition zone vegetation complex of Florida Bay is important to fauna as a food source and as refuge, supporting a number of animal species that inhabit the zone either transiently or as resident species (Ley and McIvor 2002, Lorenz et al. 2002). Only a small group of vascular plant and macroalgae species are adapted to grow in the wide-ranging and rapidly changing salinity conditions of the transition zone. Most freshwater plants cannot survive salinity exposure, particularly above mesohaline levels. Likewise, most true seagrasses cannot survive the sustained (several months) freshwater conditions common in the transition zone. Submersed vegetation in the ponds and channels of the Florida Bay transition zone has been studied relatively little, usually in localized areas (Montague et al. 1998, Morrison and Bean 1997, Tabb and Manning 1961, Tabb et al. 1962, Zieman 1982). Available data show that the vegetation of the transition zone is dominated by characteristic plants common in fresh water and brackish water, including *Chara* spp. (muskgrass, a multicelled macroalga), *Utricularia* spp. (bladderwort), *Ruppia maritima* (widgeon grass, a bushy, fanlike underwater freshwater plant that has a high tolerance for salinity and alkalinity) and *Halodule wrightii* (shoal grass, a seagrass that can withstand a wide range of temperatures and salinity).

The distribution of the macroflora in Florida Bay has changed during recent decades, probably in response to both natural and human factors. Since the end of the 1980s, freshwater flow to the Bay has increased, and the somewhat fresher salinity regime in the transition zone has most likely promoted an expansion of the freshwater and brackish-water plant assemblage, with reductions in *Thalassia* coverage in the immediate area of the transition zone (Miami-DERM 2005). The SAV community in the transition zone provides an important feeding area for wintering waterfowl such as coot, scaup, widgeon and pintail (Kushlan et al. 1982). The presence of these populations in transition zone ponds has greatly decreased in the past fifty years (Davis et al. 2005), a decline hypothesized to have been caused by overall decreases in SAV productivity and cover because of long-term increases in salinity levels and the introduction of prolonged periods of high salinity conditions into naturally oligohaline and mesohaline ponds (Morrison and Bean 1997, Montague et al. 1998, Davis et al. 2005).

Ruppia maritima is a dominant component of the transition zone SAV community and has a well-defined ecologic niche. It grows poorly in water with low water clarity or anaerobic sediments, but it has specialized features enabling survival under a wide range of salinity and high temperatures beyond those tolerated by most other submersed angiosperms (Kantrud 1991). Widgeon grass serves many ecologic functions for a variety of organisms.

Studies of the natural history of *Ruppia maritima* (widgeon grass) show the species to be not a true seagrass but a freshwater species that is unusually tolerant of salinity (McMillan 1974, Verhoeven 1975). Among estuaries worldwide, the species is found in salinity ranging from zero to full-strength seawater, although it is generally distributed and grows most rapidly where salinity is below 25 psu (Phillips 1960). *Ruppia* distribution patterns reflect the net effects of salinity and other factors on the growth, reproduction and mortality of *Ruppia* populations. The optimal salinity for *Ruppia* growth appears to be < 20 psu (Kantrud 1991), but studies of populations in Florida Bay and in other areas indicate that established *Ruppia* plants can tolerate higher salinity and even hypersalinity for extended periods. A factor that may increase *Ruppia* mortality is not simply the magnitude of salinity but the rate of change of salinity. In creeks and small ponds of the Florida Bay transition zone, where salinity can drop very rapidly, Montague and Ley (1993) found that SAV biomass was more closely correlated with salinity variance than with salinity magnitude. Rapid fluctuations have also been reported to kill *Ruppia* when salinity rose > 18 g/L in a few weeks (Verhoeven 1979). Perhaps the most important reason that *Ruppia* populations are uncommon in estuarine areas with salinity frequently above 30 psu is reproductive failure. Flowering, and hence seed production, is reported to occur only at salinity below 30 psu (Kantrud 1991), a finding consistent with the observations made on Florida's west coast by Iverson and Bittaker (1986).

Water temperature and seasonal temperature fluctuations also influence reproductive success (particularly germination) and may be important considerations in *Ruppia maritima* reestablishment, particularly in environments with widely fluctuating or high salinity. (Kantrud 1991; Montague et al. 1989) Other interactive factors that potentially influences reproductive success include dissolved-oxygen availability Kantrud (1991), hydrogen sulfide concentrations in the sediment, high concentrations of organic matter (> 10 percent of dry weight) and low concentrations of iron in the sediments (Koch et al. 2001).

Eastern Zone

Eastern Florida Bay is composed of the Barnes/Card Sound Complex, enclosed sounds (including Long, Little Blackwater, Blackwater, Buttonwood and Little Buttonwood sounds) and Tarpon Basin (**Figure 3** and **Figure 6**). The northeastern region of Florida Bay is not significantly affected by tides and is isolated from influence by the marine waters of the Atlantic and Gulf of Mexico. Salinity in the embayments along the northern boundary of the Northeast region responds very rapidly to rainfall and inflow from estuarine creeks in the mangrove swamp. High flow causes dramatic freshening in the small bays along the northern boundary. Subsequently, fresh water from these embayments slowly mixes with more saline Florida Bay waters to the south and southwest over a period of weeks to months (ECT Inc. 2005).

These basins are primarily wind-driven, tide-driven systems. Long Sound and Little Blackwater Sound are periodically influenced by freshwater runoff from the mainland (Taylor Slough/C-111 basins). The area is characterized by broad, rounded depressions and considerable freshwater influence. On an annual basis, this portion of the Bay is the one most influenced by rainfall and surface runoff and exhibits the largest range of salinity values.

Relative to the central and western Bays, the salinity regime in the eastern Bay is more sensitive to water control operational policies, specifically those governing the working of the L-31W/C-111 canal system discharging fresh water into lower Taylor Slough and wetlands areas south of the C-111 Canal. Meanwhile, the lack of tidal passes prevents the mixing in of water from the Atlantic Ocean in this zone, contributing to the creation of extended periods of high or low salinity (McIvor et al. 1994). All these factors may have been exacerbated by construction of the Overseas Highway and by sediment accumulation resulting from a relative absence of hurricanes in recent decades.

Central Zone

Central Florida Bay (**Figure 3**) is characterized by small basins, mud banks, shallow water, restricted tidal flow, poor circulation and high evaporation rates. These conditions tend to concentrate salt and dissolved organic material within this central zone. The central part of Florida Bay receives small amounts of direct freshwater inflow from McCormick Creek into Terrapin Bay, or from Alligator Creek into Garfield Bight (**Figure 7**). During times of low rainfall and high evaporation the central region can become hypersaline with values often above 40 and historically as high as 70 psu (Boyer and Jones, 2003; Robblee et al., 1991b). High salinity can persist in this central region for periods of weeks to months to years (as it did in the late 1980's), indicating that, like the northeastern region, waters of the central region have a relatively long residence time.

The direct inflow of surface water is limited by the lack of creeks (only one) and the occurrence of a low ridge (Buttonwood Embankment) along the northern shoreline. In order for surface water to flow from the Everglades into central Florida Bay, water levels (or stages) in the upstream marshes must exceed the Buttonwood Embankment elevation.

Figure 7. General Locations and Features of the Central and Western Zones in Florida Bay.

Atlantic Transition Zone

The southern region of Florida Bay along the Atlantic transition zone (**Figure 3**) is similar to the west region except that it receives influence from the Atlantic Ocean through the middle Keys passages. This zone is also a source of water to the coral reef areas of the Florida Keys National Marine Sanctuary (FKNMS).Tidal flow permits coral and other invertebrate larvae to enter Florida

Bay. Hard-bottom communities, comprises sea whips, sea plumes and other gorgonian corals, are found in depths of 4 to 7 feet of water. These habitats are swept by tidal currents and thus retain only a thin layer of loose sediments on the rocky limestone substrate. Surface water is much clearer within the Atlantic transition zone than in other zones because of the influence of the Gulf Stream and Atlantic Ocean, and salinity levels on average are lower here than in the central and western Bays, staying near those of seawater (35-41 psu). Tidal exchange in the Atlantic transition zone occurs primarily through the major passes and under-bridge areas that connect Florida Bay to the ocean.

Western Zone and Gulf Transition Zone

Western Florida Bay (**Figure 3**) features extensive shallow carbonate mud banks, but is the least isolated, sharing an open boundary with the Gulf of Mexico. The western zone experiences relatively robust tidal exchange with the Gulf of Mexico, keeping salinity at near-marine conditions in all but the very driest years. Residence times in the western region are shorter than in the central and northeastern regions. Salinity in the western region can exhibit a relatively rapid response to meteorological events such as tropical storms and cold fronts, but the range of variation is reduced relative to the northeast region. Near the zone's northern coastline, the water is turbid and appears to be influenced by runoff from major rivers (such as Shark, Broad and Lostman's rivers) along the southwest coast of Florida. The transition zone represents the area west of the Bay where depths gradually increase, and salinity remain relatively close to marine conditions as waters of the Bay merge with those of the Gulf of Mexico.

GEOLOGY AND SEDIMENTS OF FLORIDA BAY

Florida Bay is separated from the Atlantic Ocean and the Straits of Florida by a nearly unbroken ridge of Pleistocene coralline limestone (the Key Largo formation) that makes up the nearly continuous barrier of the Florida Keys (McIvor et al. 1994). Florida Bay is compartmentalized into basins (locally called lakes) by a series of carbonate mud banks. These mud banks lie atop an almost planar surface of Pleistocene pelletoidal lime packstone (grain-supported carbonate rocks) and grainstone (grain-supported carbonate rocks with no mud) (a.k.a. Miami Limestone: Perkins 1977). This microkarst has solution holes several centimeters deep. The mud banks are of biogenic origin and contain the skeletal remains of calcareous blue-green algae, seagrass epiphytes (spirorbid polycheates, soritid foraminifers, encrusting coralline algae), mollusks and stony corals (Stockman et al. 1967, Nelson and Ginsburg 1986, Frankovich and Zieman 1994). From the Florida mainland the Bay's underwater surface elevation slopes downward toward the southwest, such that bedrock is about 1.5 meters below mean low water in northeast Florida Bay and about three meters below mean low water along the southwest margin of Florida Bay (Perkins 1977, Wanless and Tagett 1989). The slope of the limestone basement of Florida Bay and the rise in sea level during the Holocene (the present age) led to a gradual flooding of the Bay. The southwest portion of the Bay flooded with seawater about 4,500 years before present, and the eastern parts of Florida Bay flooded as recently as 1,500 years before present (Enos and Perkins 1979).

Geologic Setting

The Florida peninsula is part of a much wider submersed plateau, the Floridan Plateau (Parker et al. 1955). The core of the Floridan Plateau is composed of igneous and metamorphic rocks thought to be an extension of the Appalachian Mountains (Perkins 1977). Overlying this core in the south Florida region are more than 15,000 feet of sedimentary deposits ranging in age from Cretaceous (or possibly earlier) (last part of the "age of dinosaurs") to Quaternary (the Pleistocene plus the Holocene) (Perkins 1977). Pleistocene sediments in south Florida are of particular interest because they record different sea level stands that occurred partially in response to continental glaciation and interglacial periods during the Pleistocene epoch (Parker et al. 1955). The Pleistocene deposits underlying Everglades National Park include the Fort Thompson Formation and the Miami Limestone.

The Fort Thompson Formation consists of alternating deposits of marine carbonates, brackish-water carbonates and freshwater carbonates. The marine units are thought to correlate with high sea level stands, while the freshwater beds represent periods of low sea level and emergence (Perkins 1977). According to studies based on cross sections constructed by Fish and Stewart (1991), the Fort Thompson Formation ranges in thickness from 3 to 15 meters, thickening slightly to the east.

The Miami Limestone, formerly known as the Miami Oolite, overlies the Fort Thompson Formation. It is composed of massive to cross-bedded sandy oolitic deposits underlain by bryozoan limestones (Hoffmeister 1974). The oolitic facies crop out along the eastern edge of ENP, thinning to the west. Most of the outcrops of the Miami Limestone in ENP are a combination of bryozoan fossils, lime peloids and some ooids. Exposure to rain, fresh groundwater and acids from decaying organic matter has created numerous pits, pockets and solution holes in the ENP bedrock (McNeill et al. 2000).

Surface Sediments and Soils

Overlying the Miami Limestone bedrock throughout ENP are various types of deposits formed both by terrestrial processes and by the influence of sea level changes. Peat and muck soils form in the Everglades areas in which fresh water covers the surface most of the year and organic material accumulates. These mucky soils are generally black and fine-grained and are composed predominantly of sawgrass or woody materials (on tree islands and hammocks) (McNeill et al. 2000). Freshwater marls precipitate and accumulate in the open prairies and in the deeper sloughs (Taylor and Shark). These carbonate marls are precipitated by cyanobacteria mats when the prairies are flooded, and in the southern Everglades they have reached thicknesses of up to 50 cm (McNeill et al. 2000). Mangrove peat, formed primarily from the decay of red mangrove, is deposited along the seaward edges of ENP. Another coastal deposit known as Flamingo Marl forms a levee 1 to 2 feet high along the northern shore of Florida Bay. Flamingo Marl is composed of aragonitic mud and shell and is easily eroded and transported by storms, wave surges and strong winds. A generalized cross section of shallow sediments overlies bedrock from Florida Bay to ENP is shown in **Figure 8**.

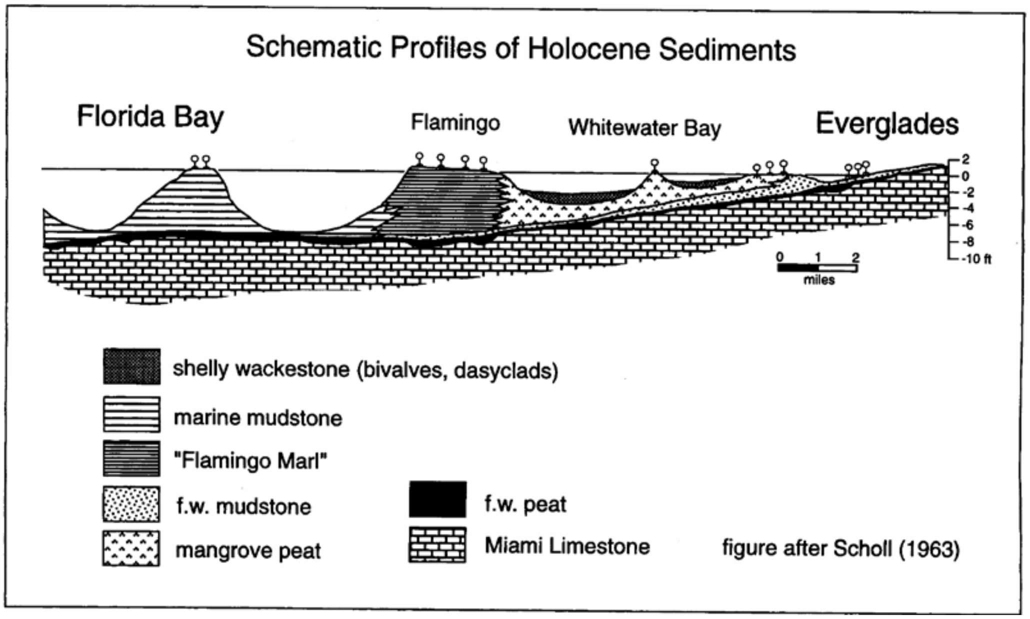


Figure 8. **Cross Section of Sediments over Bedrock: Florida Bay to ENP (McNeill *et al.* 2000).**

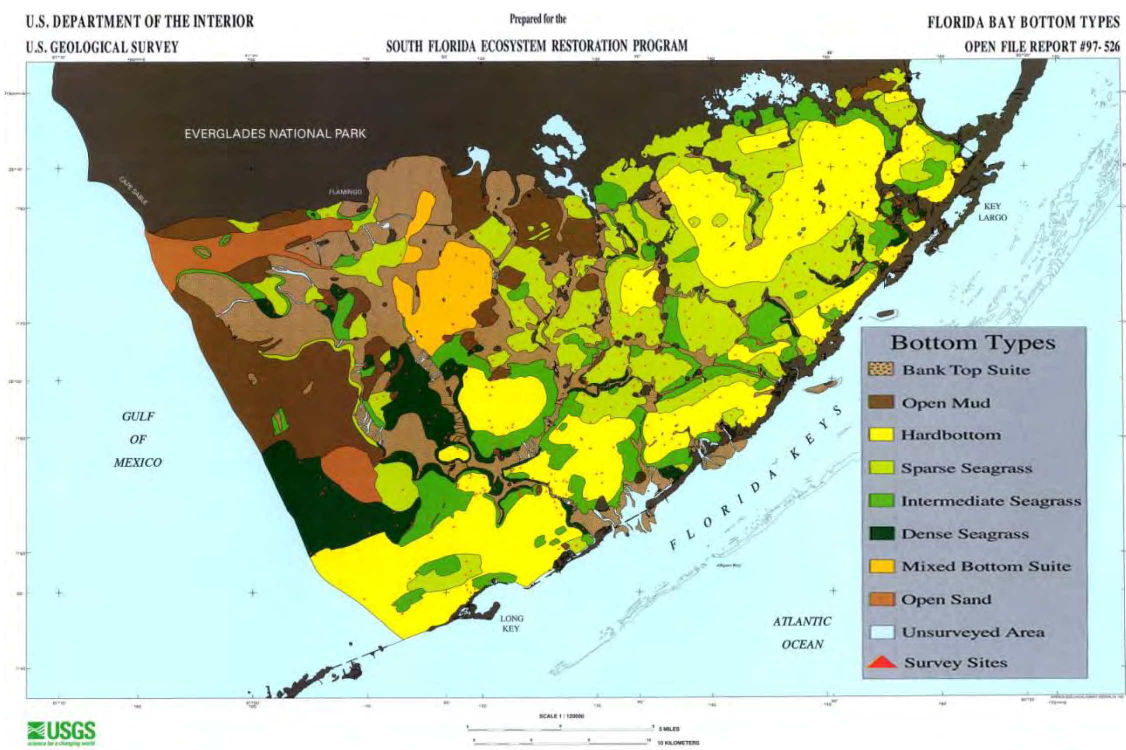


Figure 9. **Map of Bottom Types in Florida Bay (Prager and Halley 1997).**

Florida Bay Bottom Types

Florida Bay is a lagoonal system, enclosed by the Florida mainland and the islands and shoals of the Florida Keys. The Bay bottom is composed of deposits of lime mud, much of which accumulates on mud banks. These mud banks are mostly linear and divide the Bay into smaller basins (Tucker and Wright. 1990). A 1997 USGS (US Geological Survey) survey of Florida Bay identified several different general bottom types, including bank top suites (also called mud banks), open mud, hard bottom, seagrass cover (sparse, intermediate and dense), mixed bottom suite and open sandy areas (Prager and Halley 1997).

- Bank top suites (mud banks) typically occur in water depths of less than 0.6 meters and are complex linear features made of carbonate mud, sand and/or gravel.
- Open mud areas are predominantly carbonate mud, with no significant seagrass cover or benthic fauna other than algal mats.
- Hard-bottom areas also have little seagrass cover but differ from open mud areas in that they have only up to 5 cm of sediment overlying the limestone bedrock. Hard-bottom areas may contain karstic depressions, which can collect sediment and support grass patches.
- Seagrass cover types are organized into sparse, intermediate and dense categories, based on bottom exposure and sediment thickness.
- The mixed bottom suite type is highly variable, with irregular patterns of seagrass density and open mud areas. The mixed bottom suite is seen in the west-central region of the Bay.
- Open sandy areas occur in the Gulf transition zone and are typically composed of coarse shelly carbonate sand with no significant benthic fauna.

Major Aquifer Systems

Two major aquifer systems underlie the ENP— the Floridan Aquifer System (FAS) and the Surficial Aquifer System (SAS). The Floridan Aquifer System is geographically extensive, occurring throughout Florida and in parts of adjacent states. In Miami-Dade County, the top of the FAS is 950 to 1,000 feet below sea level (Fish and Stewart 1991). The FAS is overlain by a thick sequence of green clay, silt, limestone and fine sand collectively referred to as the intermediate confining unit. The Surficial Aquifer System (SAS) overlies this intermediate confining unit and is the source of fresh water for most of southeast Florida. **Figure 10** shows a generalized cross section of the aquifer systems in Miami-Dade County.

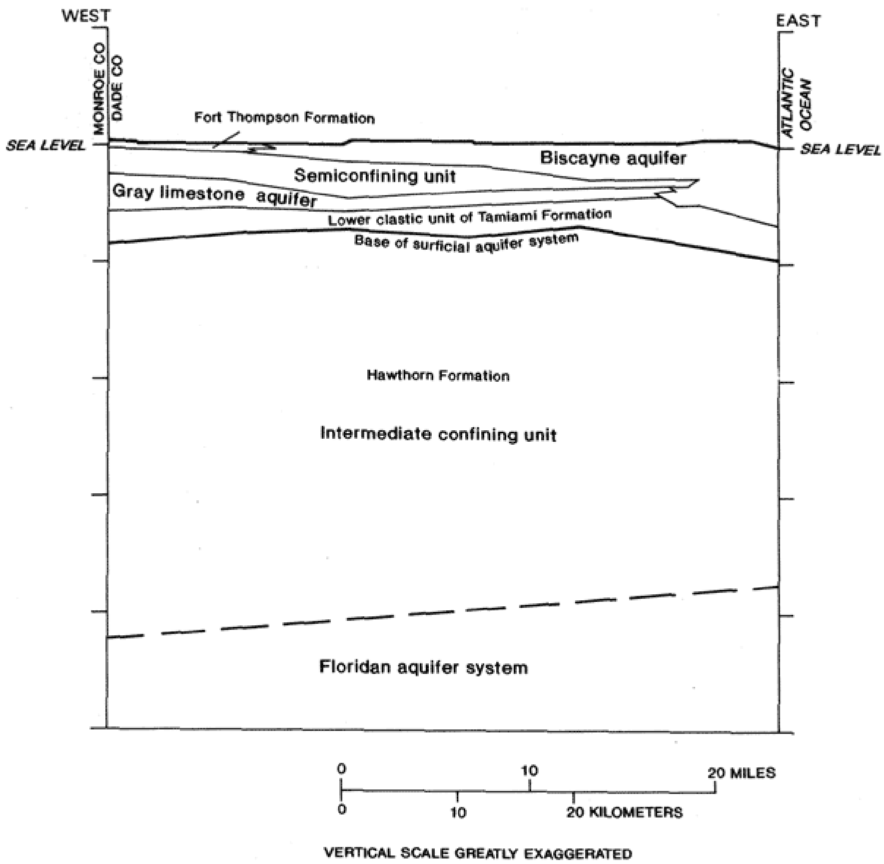


Figure 10. General Cross Section of Major Aquifer Systems in Miami-Dade County (Fish and Stewart 1991).

Floridan Aquifer System

The Floridan Aquifer System (FAS) is a confined aquifer system made up of a thick sequence of limestone types, with dolomitic limestone and dolomite commonly found in the aquifer's lower portions. The Floridan Aquifer System is separated from the Surficial Aquifer System by the sediments of the intermediate confining unit, which is also referred to as the Hawthorn Group.

Less permeable carbonate units, referred to as the middle confining unit, separate the Floridan Aquifer System into two major aquifers called the Upper and Lower Floridan Aquifers (UFA and LFA). The Upper Floridan Aquifer is composed of fossiliferous limestones from the Suwannee, Ocala and Avon Park formations. This middle confining unit is relatively less permeable than the UFA and LFA, and it separates the brackish water of the Upper from the more saline water of the Lower. The Lower Floridan Aquifer is composed of dolostones of the Oldsmar and upper Cedar Keys formations. Groundwater in the LFA is close to seawater in composition and upwells into the middle confining unit through fractures (Meyer 1989).

Surficial Aquifer System

The Surficial Aquifer System is an unconfined aquifer system, meaning that the groundwater is at atmospheric pressure and that water levels correspond to the water table. It is composed of solutioned limestone, sandstone, sand shell and clayey sand and includes sediments from the water table down to the intermediate confining unit (Hawthorn Group). The SAS sediments have a wide-ranging permeability and have been locally divided into aquifers separated by less permeable units. The best known of these is the Biscayne Aquifer. One of the most productive aquifers in the world, the Biscayne Aquifer (**Figure 11**) extends from coastal Palm Beach County south, including almost all of Broward County, all of Miami-Dade County and portions of southeastern Monroe County. Another less widely utilized aquifer in the SAS is the gray limestone aquifer, which lies below and west of the Biscayne Aquifer, extending into Hendry and Collier counties. The transmissivity of the SAS varies geographically but is reported to be about 300,000 feet squared per day or more throughout central and eastern Miami-Dade County and increases to 1,000,000 feet squared per day toward Florida Bay (Fish and Stewart, 1991).

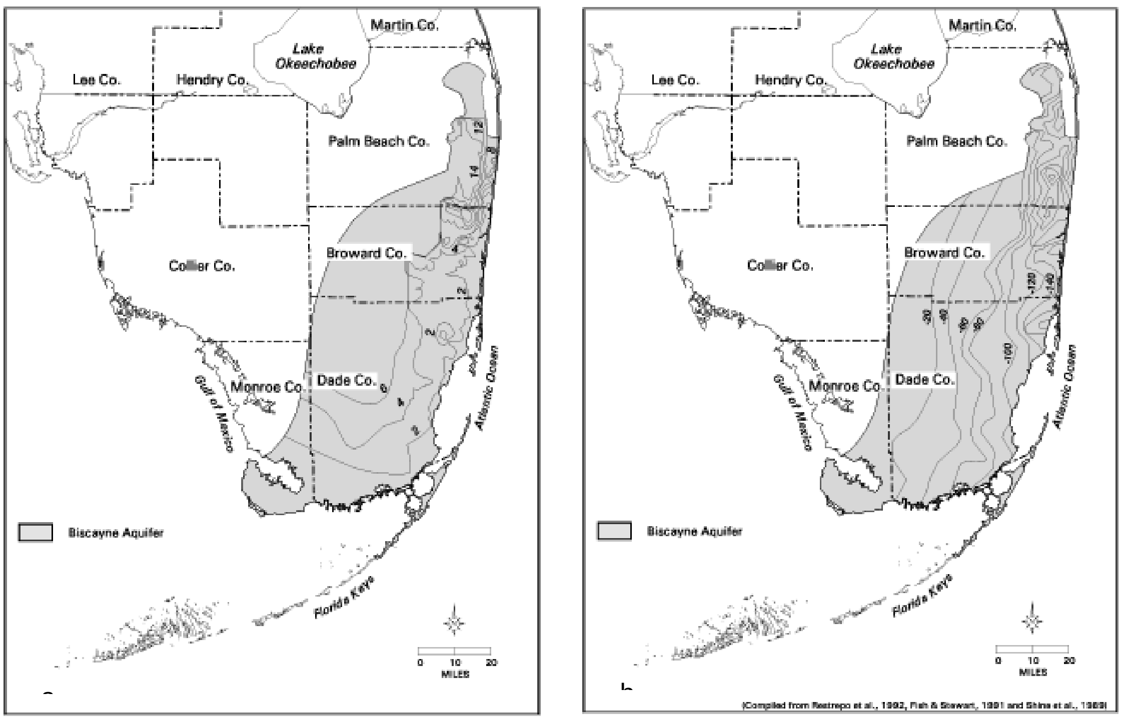


Figure 11. Location of the Biscayne Aquifer in Eastern Miami-Dade, Broward and Palm Beach Counties with a) Average Aquifer Depth and b) Elevation of the Surface of the Aquifer (contour lines are feet NGVD).

The Biscayne Aquifer is composed of interbedded, unconsolidated sands and shell units layers with varying thickness of consolidated, highly solutioned limestones and sandstones. In general, the Biscayne Aquifer contains less sand and more solutioned limestone than does most of the SAS. The Biscayne Aquifer is one of the most permeable aquifers in the world and has transmissivities in excess of seven million gallons per day (MGD) per foot of drawdown (Parker et al. 1955).

The major geologic deposits that constitute the Biscayne Aquifer include Miami Limestone, the Fort Thompson Formation, the Anastasia Formation and the Key Largo Formation. The base of the Biscayne Aquifer is generally the contact between the Fort Thompson Formation and the underlying Tamiami Formation of Pliocene to Miocene Age. But in places where the upper unit of the Tamiami Formation contains highly permeable limestones and sandstones, the areas would also be considered part of the Biscayne Aquifer if the thickness exceeds 10 feet. Hydraulic conductivity values in the most permeable sections of the aquifer commonly exceed 10,000 feet per day (Fish and Stewart 1991).

The gray limestone aquifer is composed of gray, shelly limestone with abundant shell fragments and sand. It is below and west of the Biscayne Aquifer, extending over most of central-south Florida, including eastern and central Collier and southern Hendry counties. The hydraulic conductivity of the gray limestone aquifer generally increases from east to west and ranges from approximately 200 to 12,000 feet per day. Transmissivity values range from greater than 50,000 ft^2/ day west of Miami-Dade and Broward counties to greater than 300,000 ft^2/ day in eastern Collier County (Reese and Cunningham 2000). For most of its extent, the gray limestone aquifer is confined by clays of low hydraulic conductivity, sand, clayey sand and mudstone.

Saltwater Intrusion

The inland movement of salt water is a major resource concern in the coastal areas of Miami-Dade County and can significantly affect fresh water availability in areas adjacent to saline water bodies. When water is withdrawn from the surficial aquifer at a rate that exceeds its recharge capacity, the amount of freshwater head available to impede the migration of salt water is reduced, and saltwater intrusion becomes likely. The groundwater hydrology of the Lower East Coast Planning Area has been permanently altered by urban and agricultural development and construction of the C&SF Project. Construction of a series of canals has drained both the upper portion of the Biscayne Aquifer and the freshwater mound behind the coastal ridge. The result has been a significant decline in groundwater flow toward the ocean, allowing the inland migration of the saline interface during dry periods. Large coastal wellfields have also been responsible for localized saltwater intrusion problems. Construction of coastal canal water control structures has helped to stabilize or slow the advance of the saline interface, although isolated areas still show evidence of continued inland migration of salt water (SFWMD 2000a).

More recently, several wells in the cities of Hollywood, Hallandale and Dania were taken out of service because of saltwater contamination as the recharge capacity of the aquifer was exceeded. The District's consumptive use permitting (CUP) criteria include denial of permits that would cause harm to the water resources because of intrusion by saline water. Section 3.4, Saline Water Intrusion, of the District's Basis of Review for Water Use Permit Applications (SFWMD 2003) describes harmful saline water intrusion as occurring when withdrawals result in the further movement of a saline water interface to a greater distance inland toward than would otherwise occur due to seasonal fluctuations; climatic conditions such as drought; or operation of the Central and Southern Flood Control Project, secondary canal, or stormwater systems. There is potential for withdrawals to permanently move the saline interface inland, reducing the quality and quantity of water available at existing wellfields and impeding future withdrawals at favorable locations (near population centers and treatment plants).

Historically, the District's Consumptive Use Program (CUP) has required water users to maintain a minimum of one foot of freshwater head between their wellfields and saline water as a guideline for the prevention of saltwater intrusion. This guideline, in combination with a monitoring program for saltwater intrusion, has been largely successful in preventing salt water from occurring based on consideration of individual permits and utility operations. The Lower East Coast Water Supply Plan (LEC Plan) has taken a more comprehensive view of the potential for saltwater intrusion by identifying areas that are most vulnerable and developing proactive measures to reduce the occurrence of, and better manage, saltwater intrusion.

Tidal Features

Florida Bay and the western coast of Everglades National Park are typically described as low-energy coastlines. Water circulation within Florida Bay is restricted by numerous carbonate mud banks that divide the Bay into a series of basins (locally called lakes). Tides along the western margin of Florida Bay range from a Gulf of Mexico–influenced mixed semidiurnal tide with a mean tidal range of 61 cm in the Flamingo area, to an Atlantic Ocean–influenced semidiurnal tide with a mean tidal range of 17 cm in the Long Key area (Turney and Perkins 1972, Holmquist et al. 1989b as cited in Fourqurean and Robblee 1999). Circulation within most of the Bay is primarily tidal and wind driven (Schmidt and Davis 1978). The passing of storm fronts and changes in wind direction can override lunar tides throughout Florida Bay. Annual cycles in mean water depth can cause as much as a 1-foot (30 cm) difference in mean water levels over the year. Water depths are greatest in the August-November period and lowest during the February-May period (Holmquist et al. 1989b as cited in Fourqurean and Robblee 1999). Exposed at low tide, the mudflats provide valuable feeding areas for a number of wading bird species.

The interconnected shallow mud banks that divide the Bay into more than 40 basins act as a barriers that limit water exchange among the basins, particularly those basins such as Whipray and Rankin Lake, which are located within the interior central portions of the Bay. Tidal flushing (as indicated by tidal amplitude) is greatest in western Florida Bay adjacent to the Gulf of Mexico, and tidal flushing also occurs in portions of eastern Florida Bay influenced by the Atlantic Ocean, with the rest of Bay experiencing minimal tidal fluctuations. Reduced flushing, when coupled with low freshwater inflows and high evaporation rates, is a significant factor that can lead to hypersaline conditions within central Florida Bay (McIvor et al. 1994).

LAND USE

The land use map provided here represents all lands that potentially provide surface water flows to Florida Bay. Such lands include Rocky Glades and the Taylor Slough/C-111 and Long Pine basins located directly north of Florida Bay, as well as the Shark River Slough drainage basin, which may influence salinity patterns within western Florida Bay during periods of high rainfall. Land use patterns were based on 1995–2000 aerial photographs analyzed in terms of a combination of Level 2/Level 3 categories from the Florida Land Use and Cover Classification System (FLUCCS). **Figure 12** shows composite of 1995–2000 Level 2 land cover of the Florida Bay watershed. Agricultural lands constitute about 5.8 percent of the watershed and for the most part lie east of the boundaries of ENP within the C-111 basin. The largest agricultural land use consists of cropland and pasture (4 percent of the watershed), tropical tree farms (1.1 percent), nurseries (0.5 percent) and specialty farms (0.1 percent) as shown in **Table 1**.

Because the large majority of the watershed lands lie within the boundaries of ENP, they remain undeveloped and continue as 1) vegetated nonforested wetlands (includes freshwater and saltwater marshes, wet prairies), 2) wetland hardwood forests (includes mangroves, forested ponds and sloughs, willows, mixed shrubs and some exotics, 3) shrub and brushland, 4) upland and wetland coniferous forests and 5) other vegetation and beaches. All of these together cover approximately 734,000 acres or 92 percent of the study area.

Urban land use within the watershed is low, representing less than 1 percent of the watershed. Such uses consist of residential units (of low, medium and high density), roads, mobile homes, utilities, disturbed land, industry, institution, open land and the like located west of the cities of Homestead and Florida City and also in the Redlands and the “eight and one-half square mile area” (a residential area within the East Everglades).

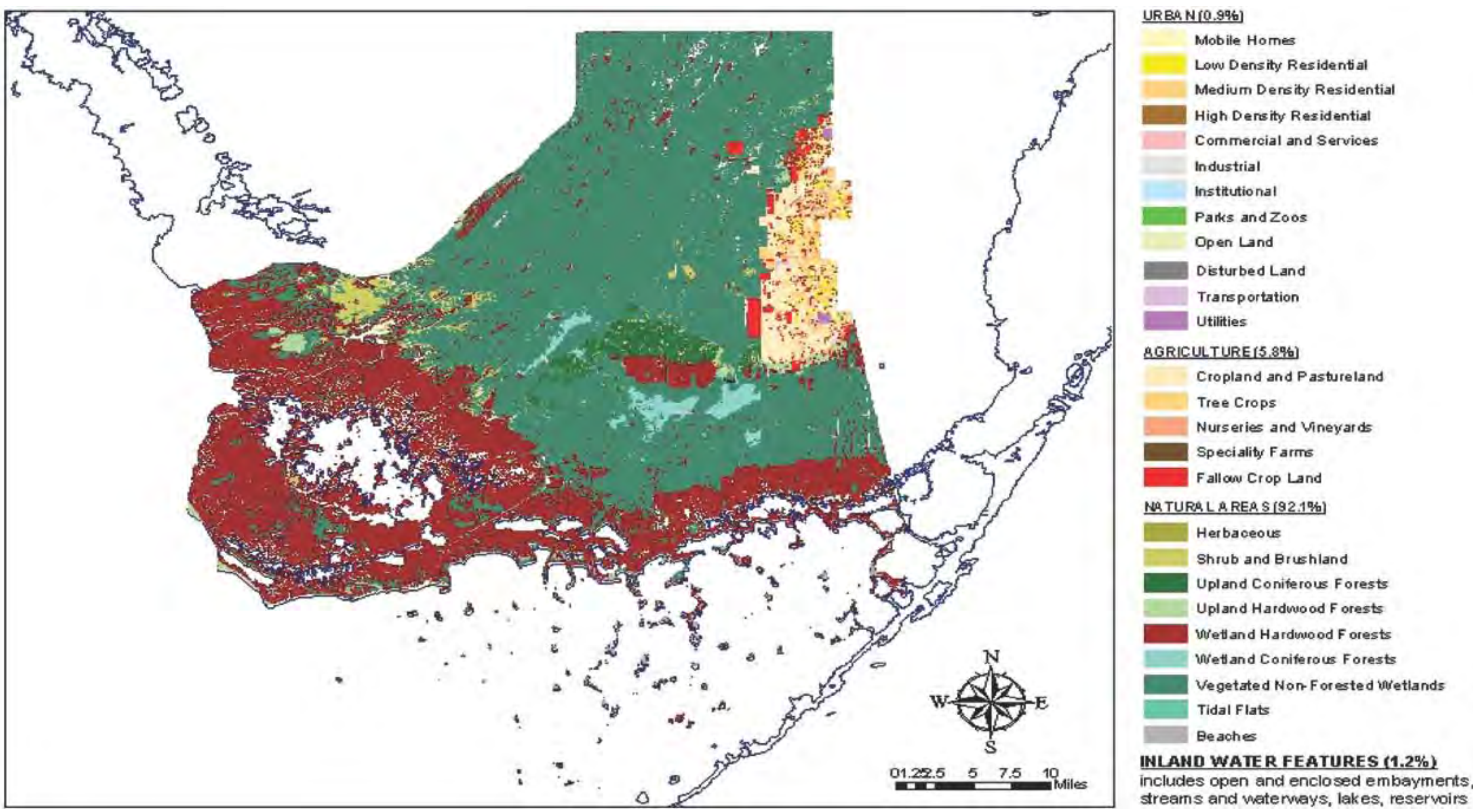


Figure 12. Composite of 1995–2000 Florida Bay Watershed Land Cover (FLUCCS, Level 2).

Table 1. Florida Bay Watershed Land Use.

Rank*	Land Use Description (FLUCCS Level 2)	Acres	Percent of Total
	NATURAL AREAS		
1	Vegetated nonforested wetlands (freshwater and saltwater marshes, wet prairies)	436,771.2	54.80
2	Wetland hardwood forests (mangroves, forested ponds and sloughs, willows, mixed shrubs, some exotics)	243,135.7	30.50
4	Shrub and brushland	14,316.7	1.80
5	Upland coniferous forests	13,409.3	1.68
6	Wetland coniferous forests	11,537.5	1.45
7	Upland hardwood forests	9,810.0	1.23
10	Beaches (other than swimming)	4,262.7	0.53
18	Vegetation	674.0	0.08
25	Nonvegetated (tidal flats, shorelines, oyster bars)	42.2	0.01
27	Herbaceous	28.5	0.00
	Subtotal	733,987.8	93.02
	AGRICULTURAL		
3	Cropland and pastureland	32,855.0	4.10
8	Tree crops	8,972.6	1.13
11	Nurseries and vineyards	3,661.4	0.46
14	Specialty farms	1,112.6	0.14
	Subtotal	46,601.6	5.85
	URBAN		
12	Low-density residential	2,739.7	0.34
15	Transportation	1,111.3	0.14
16	Mobile homes	784.6	0.10
17	Utilities	702.4	0.09
19	Medium-density residential	617.3	0.08
20	Disturbed land	384.6	0.05
21	Industrial	150.8	0.02
22	High-density residential	147.5	0.02
23	Institutional	97.1	0.01
24	Open land	44.9	0.01
28	Commercial and services	26.1	0.00
29	Parks and zoos	25.9	0.00
	Subtotal	6,866.6	0.86
	INLAND WATER FEATURES		
9	Enclosed and open embayments to Gulf of Mexico	8,437.1	1.06
13	Streams and waterways	1,168.5	0.15
26	Lakes and reservoirs	34.4	0.00
	Subtotal	9,640.1	1.21
	Grand Total	797,061.6	100.00

* ranking (largest to smallest) based on acreage of each land use type within the watershed

HYDROLOGY

Climate, Seasonal Weather Patterns and Rainfall

Florida is subtropical and experiences a tropical-savannah type climate characterized by a relatively warm wet season (generally, May through October) and a cooler dry season (November through April). Mean annual temperature is 24.5^{o} C, with a mean monthly low temperature of 20^{o} C in January and a mean monthly high temperature of 28^{o} C in August (McIvor et al. 1994). Winds in south Florida, including Florida Bay, follow a regular seasonal pattern: in summer, weak southeast trade winds and daily sea breezes; in fall, persistent northeast winds; and in winter, cold fronts cause moderate increases in wind speed and clockwise rotation of wind direction.

The area experiences distinct wet and dry seasons, high rates of evapotranspiration (ET) and climatic extremes of floods, droughts, hurricanes and tropical depressions. During the dry season, cold fronts pass through the region on an approximately weekly basis with accompanying increased wind speeds and clockwise rotating wind directions (Lee et al. 2003). During the wet season, showers occur nearly every day in response to afternoon sea breezes. Tropical storms (tropical depressions and hurricanes) typically occur during the wet season on a fairly frequent basis of about once every 1–2 years. These natural factors, together with regional water management operations, are the primary driving forces defining the amount of fresh water that flows toward Florida Bay.

Seasonal rainfall patterns in south Florida resemble the wet and dry season patterns of the humid tropics more than the winter and summer patterns of temperate latitudes. The wet season generally follows a bimodal pattern, with the first peak occurring in June and the second during September/October. This bimodal pattern reflects the annual movement of a high-pressure cell known as the Bermuda High. The Bermuda High migrates westward during the summer months, generally positioning its western edge near south Florida during June. The resulting southeasterly winds bring moisture into the area from the tropical Atlantic Ocean and Caribbean Sea. As this high-pressure cell moves westward and is centered over the Keys during July and August, winds generally diminish and rainfall decreases. Average winds and rainfall again increase in September and October as the Bermuda High retreats to the east again (Duever et al. 1994).

Available long-term rainfall records for land-based rainfall monitoring sites located within south Florida do not provide reliable estimates of the amount of rain that directly falls over Florida Bay. Average annual rainfall amounts in ENP generally increase north of Florida Bay. Rainfall differences between the mainland and the Bay are attributed to the fact that convective storms form primarily along the coast early in the wet season but do not form over the open water of the Bay until late in the wet season. This phenomenon produces higher rainfall measurements at the mainland stations as compared to what actually falls over the Bay (Schomer and Drew 1982). Boyer and Jones (2003) report an average annual rainfall estimate of 43.9 inches for Florida Bay for the 1993–2002 period of record. Nuttle and Teed (2002) reported an average annual rainfall of 47.8 inches for the three primary basins (Taylor Slough, C-111 and Long Pine) that provide surface flows to northern Florida Bay.

Recorded annual rainfall values can vary significantly not only from location to location but also from year to year, and interannual extremes in rainfall can have significant effects on Florida Bay's salinity regime. Trimble et al. (2001) have shown that low-frequency meteorological modes associated with the El Niño–Southern Oscillation (ENSO) and with the Pacific Decadal Oscillation can have significant effects on the variability of south Florida rainfall and the amount of water available for urban and residential water supply. Enfield et al. (2001) discuss the Atlantic Multidecadal Oscillation (AMO) and how fluctuations in the North Atlantic sea surface temperatures can affect the amount of water available to the Everglades and to south Florida's estuaries, agricultural areas and urban coastal communities.

Much of the rainfall into Florida Bay is returned to the atmosphere by evaporation from water surfaces. Hydrologic and meteorological methods are available to measure and/or estimate the combined rate at which water is returned to the atmosphere through evaporation from water surfaces and transpiration from plants. The combined processes are known as evapotranspiration (ET). Direct measurements of ET within Florida Bay range from 29.5 to 70.8 inches of water per year (Lee et al. 2003). Water budgets developed by Nuttle et al. (2003) using 31 years of historical rainfall data showed that seasonal rainfall for the Bay as a whole is nearly exactly counterbalanced by evaporation. Nuttle used an ET estimate of about 50 inches of water per year to develop his water budget for Florida Bay. This annual total falls roughly in the middle of the range (47–57 inches) of annual ET rates measured by German (2000) at nine sites located throughout the Everglades for the years 1996–1997.

Historical Hydrology

Because of the altered water flow in south Florida, an important aspect of the development of water delivery standards for the future is to understand how freshwater flow from the Everglades was delivered to Florida Bay historically, under natural conditions. Models and paleoecological studies can be helpful in creating a fairly detailed picture of the historical hydrology of the system.

At the end of the last glacial period, about 10,000 years ago, Florida looked quite different from how it looks today. Sea level was 10 to 20 m lower, the above-water portion of the peninsula was wider, the central areas of south Florida consisted of a dry sandy ridge, and the Everglades peatlands did not yet exist. Lake Okeechobee was just a shallow depression about ten feet deep with a rock and sand shoreline along its southern edge. Since that time sea level has been rising steadily, entailing a rise in groundwater levels. The Everglades peatlands began to form about 5,000 years ago (Gleason, 1972). Rising water tables and overflow from Lake Okeechobee during wet periods created a surface flow of water that continually inundated the original sand and rock substrate and supported growth of wetland plant communities. Fertilized by floodwaters from the lake and by windblown nutrients, the vast area south of the lake gradually filled with marl and organic sediments. Sea levels continued to rise, and the level of the landscape also increased over time. Accretion of sediment and soil allowed water levels in Lake Okeechobee to increase, providing additional storage and allowing water to flow out of the lake progressively later in the dry season.

After about 5,000 years, water probably flowed from the lake to the Everglades throughout most years. Between 4,500 and 3,000 years before present, rising sea levels inundated the area now known as Florida Bay. Coastal and freshwater peat and shore levee deposits, positioned by irregularities in the underlying limestone surface, were repeatedly embayed and overstepped during this inundation. The flooded and dispersed coastal deposits of the area became nuclei from which the present complex of Florida Bay islands, mud banks, bank spits and bays evolved (Wanless and Taggett 1989). By the time that humans first encountered south Florida, about 500 years ago, Florida Bay was a well-established, shallow coastal estuary with mud, sand and exposed rock bottom, mangrove shorelines and numerous small islands. Freshwater inflow occurred primarily as rainfall, as overland sheet flow across the mangrove wetlands and as flow through coastal creeks and rivers. By the early 1800s, Lake Okeechobee and its southern shoreline had reached an elevation of about 21.5 feet above current sea level, creating a substantial elevation gradient to drive the flow of water toward Florida Bay across a very gradually sloping plain, which varied in vegetation composition from north to south.

Extreme Weather Events

The Florida Keys and Florida Bay are periodically exposed to extreme weather conditions that impact resources in this system. The effects of a short-term “freeze” may be transient, but severe freezes can result in large-scale destruction of sensitive species (such as mangroves) that may take many years to recover. Nineteen such cold waves hit the Florida peninsula in the 1880–1980 period (Myers 1986).

Major hurricanes may have effects that persist for decades. A total of 22 hurricane seasons in the years between 1880 and 1980 brought one or more hurricanes apiece that affected the Florida Keys (Jaap 1984). Hurricane Donna of 1960, with its wind speeds of up to 322 km/h, was one of the most severe storms ever to strike Florida Bay. Hurricanes produce major ecological perturbations very significant in terms of their implications for long-term maintenance of the Florida Bay ecosystem. The effects of hurricanes on the Florida Bay ecosystem can be compared to and contrasted with the effects of fire on the south Florida terrestrial ecosystems. Just as the importance of fires has been recognized in the management of terrestrial ecosystems, the role of hurricanes on coastal and shallow bay communities must also be recognized (Meeder and Meeder 1989).

Many perturbations produced by a hurricane are uncontrollable, with impacts on the Florida Bay ecosystem that are impervious to human management. But major exceptions to this rule are hurricane runoff quantity and timing, tidal exchange rates and quality of runoff water. Intense periods of rapid runoff appear to be very significant in maintaining the Florida Bay ecosystem. Storms that affect the Bay bottom and coastline occur at a reasonably predictable interval of one such storm every 3 to 5 years, and storms that produce extreme freshwater runoff occur once every 6 to 7 years. The significance of tropical storms becomes clearer when these frequencies are understood.

Railroad and Causeway Construction

The Overseas Railroad from Miami to Key West was the first massive alteration by man to the marine environment of the Florida Keys and Florida Bay. Built between 1905 and 1912 by Henry M. Flagler, the railroad followed the main line of the Keys, spanning 37 miles (60 km) of open water with 17 miles (27 km) of earthen and rock-filled causeways (Corliss 1953). More than 20 million yd^3 of rock, sand and marl were used to build the embankments (Hopkins 1986). This material was blasted and dredged from land and shallow-water areas along the route of the railroad. Cohesive gray lime mud was mined extensively from Florida Bay for this purpose (Corliss 1953). Turbidity and siltation from these activities must have been on an enormous scale. Construction began on the mainland, and by 1906 the railroad extended as far south as Long Key (Corliss 1953). Former land development practices in the Florida Keys have included dredging of canals, boat slips, marina boat basins and deep-water access channels to the Atlantic Ocean, Florida Bay and Gulf of Mexico. These largely unrestricted operations were most numerous between 1955 and 1970. In 1971, the State of Florida enacted a moratorium on such activities (Voss 1973).

Water Management Changes

Sea level in the Florida Bay area has risen by approximately seven inches during the past century, while water levels in Lake Okeechobee and the Everglades have fallen substantially, in part as a result of drainage activities. Beginning in the late 1800s, efforts to drain the main body of the original Everglades altered hydrologic conditions irreversibly throughout south Florida. Major changes to the patterns of freshwater flow into Florida Bay appeared with the construction of large drainage canals throughout the Everglades starting in the early 1900s. Water management efforts interrupted the movement of water southward out of Lake Okeechobee into the Everglades and increased the volume of water draining east toward the Atlantic Ocean. The result was a general lowering of water levels, reducing both surface and subsurface flows southward toward Florida Bay. Construction of the C&SF project, beginning in the 1950s, improved the ability to manage flows and water levels in the Everglades and more directly influence flows into Florida Bay (Light and Dineen, 1994).

Water management activities that currently have the most direct effect on the supply of fresh water to Florida Bay began in the 1960s (**Table 2**) and continued through completion of the C&SF Project in the 1970s. The completion of the Tamiami Trail levee and the S-12 flow control structures in 1962 and the C-111 Canal in 1968 gave water managers full capacity to regulate the flow of surface water into Everglades Park and adjacent estuarine areas, including Florida Bay.

By the early 1970s, sufficient concern had arisen over water management's consequences for Everglades National Park and Florida Bay to motivate a series of actions intended to mitigate the effects of the structures and practices recently put in place. Modifications to the water management system and associated operations continued over the next 30 years.

Beginning in the late 1970s, a program of minimum prescribed water deliveries set monthly targets for the quantity of water to be supplied across Tamiami Trail to Shark Slough, through the C-111 Canal to Florida Bay and for discharge into the headwaters of Taylor Slough. The Experimental Water Deliveries program later replaced the minimum monthly delivery targets and continued to pursue the objective of increasing water deliveries to Florida Bay.

Beginning in the early 1970s and continuing until about the mid-1980s, the implementation of the South Dade Conveyance System (SDCS) project enhanced flood protection in southern Miami-Dade County and further altered the hydrology of the area east of the headwaters of Taylor Slough, near the main entrance to Everglades National Park. Records of surface water discharge at Taylor Slough bridge (TSB) and at the S-175 and S-18C structures document that a large and very significant and durable increase in surface flow into the Taylor Slough/C-111 basin began around 1980 and has continued (**Figure 13**).

In the early 1980s, flooding concerns in Miami-Dade County prompted additional operational changes to the SDCS in an attempt to alleviate flooding and also provide additional fresh water to Everglades National Park. Further operational modifications were made in the 1990s in an attempt to restore flows and water levels in Taylor Slough. Structural changes were also made in order to implement a more even distribution of flows from the C-111 Canal across the mangroves.

South Florida Water Management Model

Simulation models have become the only feasible means of assessing systemwide impacts of the various proposed modifications to the water resources system in south Florida. The South Florida Water Management Model (SFWMM), developed specifically for the south Florida system, is currently the best available tool that can simulate the complexities of the water control system and operational rules of proposed regional-scale water management alternatives and provide adequate information for making water management decisions (SFWMD, 1999). The SFWMM is a regional-scale computer model that simulates the hydrology and the management of the water resources system from Lake Okeechobee to Florida Bay. It covers an area of 7,600 square miles using a mesh of 2-mile-square (4 square miles) cells.

Table 2. Water Management Activities Affecting Florida Bay, 1960–2000.

Period	Water Management Activities
1960–1969	Construction of the levee and S-12 control structures completed in 1962, blocking free flow of surface water to Everglades National Park (ENP) from wetland areas north of Tamiami Trail. Initially there are no outlets through this dike to supply water to northeast Shark Slough or headwaters of Taylor Slough.
	Construction begins on C-111 and associated canals that will alter the hydrology in south Miami-Dade County, adjacent to the headwaters of Taylor Slough and north of the freshwater wetlands and mangrove transition in the southwest portion of the ENP. Initially the S-173 structure limits the amount of flow that can occur from the wetlands north of Tamiami Trail into southern Miami-Dade County and Florida Bay.
	Drainage of south Miami-Dade agricultural lands decreases water flow to the mangrove transition zone through the finger glades.
	C-111 Canal and its control structures are completed in 1968. The C-111 Canal establishes a hydrologically significant new breach for flow through the coastal ridge, parallel to Taylor Slough. Earthen plug is installed at present location of S-197 structure to maintain water levels above sea level in the lower reaches of the C-111 Canal and thus prevent saltwater intrusion.
1970–1979	Congressionally mandated Minimum Schedule Water Deliveries (MSWD) into ENP begin in 1970 in response to concerns that not enough water is reaching Taylor Slough and other areas of the ENP.
	Work begins on the South Dade Conveyance System (SDCS) needed to implement the MSWD to Taylor Slough. The first phase of work is completed in 1980 with installation of the S-332 pump to deliver water to Taylor Slough.
1980–1989	High water levels and flooding in Miami-Dade County during 1981–1983 prompt changes in the SDCS. The plug at S-197 is removed several times to allow discharge of flood waters through the C-111 Canal; this eventually leads to construction (in 1992) of the present gated control structure. Pump S-133 is installed to increase the capacity to move water from wetlands north of Tamiami Trail to southern Miami-Dade County through C-111 and L-31N canals.
	Increased flows in C-111 Canal initially discharge to wetlands and Florida Bay through Long Sound, flowing along the eastern boundary of the ENP at US Route 1. In 1987, discharge from C-111 Canal accounts for 90 percent of surface flow to wetlands north of Florida Bay. Changes in water management operations supply more water to Taylor Slough over the next five years.
	Beginning in 1983, the Experimental Water Deliveries program establishes operational goals for water deliveries to ENP, effectively replacing the MSWD goals. This program will institute a succession of changes in water management operations over the next 15 years.
1990–2000	Marked changes in the ecology of Florida Bay motivate actions to increase water deliveries to Florida Bay through Taylor Slough and redistribute discharge from the C-111 Canal west, into Joe Bay and away from Long Sound.
	Capacity of the S-332 pumps that feed water into Taylor Slough is increased in 1993 and again in 1994. Impediments to surface flow within Taylor Slough are decreased by removing a portion of the Old Ingram Highway and by modifying the bridge where the main ENP road crosses the slough (completed in 2000).
	The 1992 Modified Water Deliveries General Design Memorandum establishes a strategy to restore flow and water levels in the portion of ENP that feeds the headwaters of Taylor Slough: implementation of this plan has been delayed.
	In 1997, removal of the spoil along C-111 Canal, south of S-18C, allows a more even east-west distribution of discharge into the wetlands north of Florida Bay.

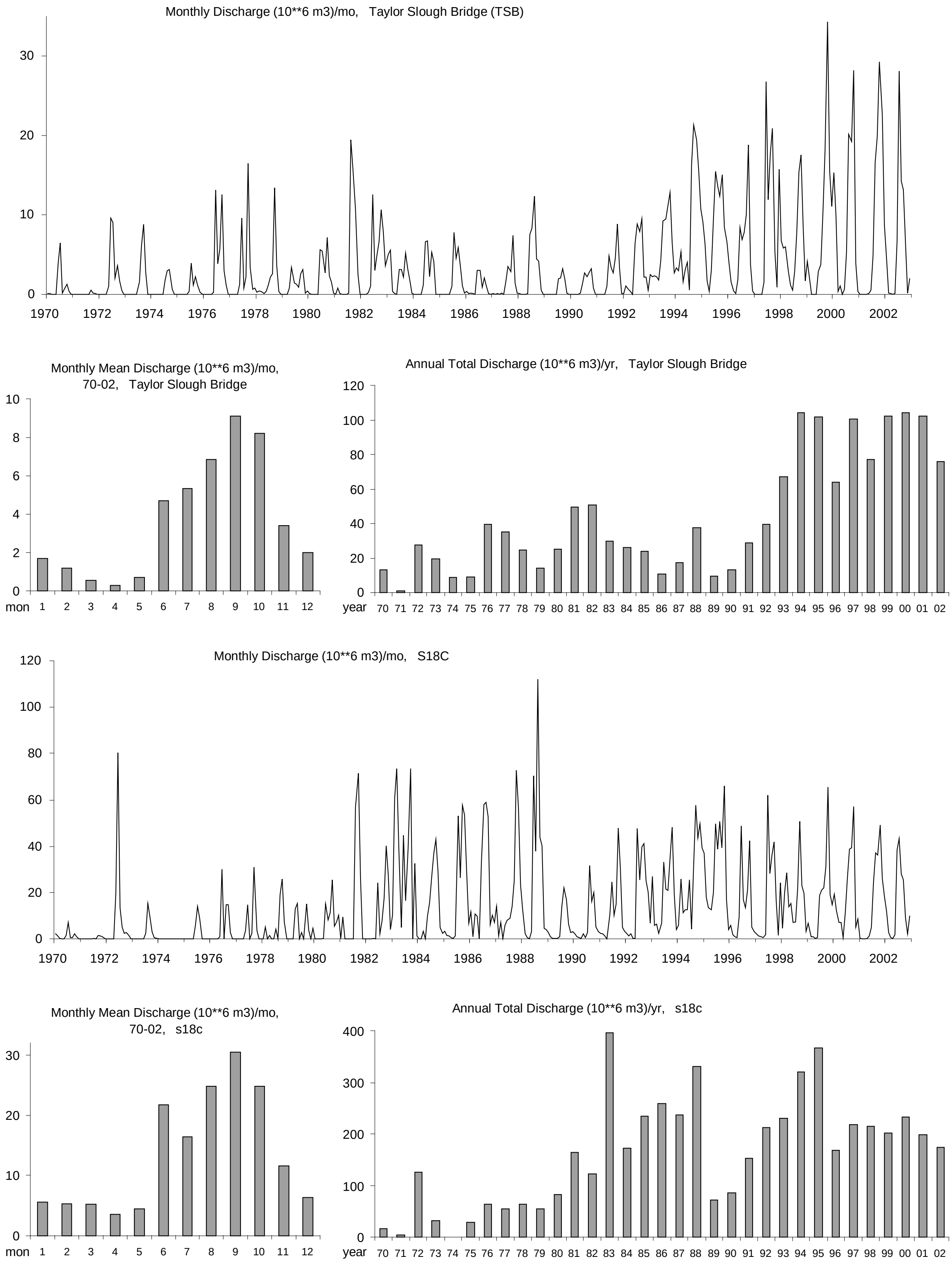


Figure 13. Freshwater Discharge into the Taylor Slough/C-111 Basins (data used for regional indices).

The model includes inflows from the Kissimmee River and runoff and demands in the Caloosahatchee River and St. Lucie Canal basins. The model simulates the major components of the hydrologic cycle in south Florida including rainfall, evapotranspiration, infiltration, overland and groundwater flow, canal flow, canal-groundwater seepage, levee seepage and groundwater pumping. It incorporates current or proposed water management control structures and current or proposed operational rules. The ability to simulate water shortage policies affecting urban, agricultural and environmental water uses in south Florida is a major strength of this model. The SFWMM simulates hydrology on a daily basis using climatic data for the 1965–1995 period, which includes many droughts and wet periods. The model has been calibrated and verified using water level and discharge measurements from hundreds of locations throughout the region within the model boundaries. Technical staffs of many federal/state/local agencies and public- and private-interest groups have accepted the SFWMM as the best available tool for analyzing regional-scale structural and/or operational changes to the complex water management system in south Florida.

The SFWMM was originally developed by the SFWMD in the late 1970s and has been improved over time in capability and scope to meet the unprecedented demand for evaluating potential changes. Version 3.5 was used in the Central and Southern Florida Flood Control Project Comprehensive Review Study (Restudy) by the USACE and SFWMD, and in 1999. Version 3.7 was used for development of the Lower East Coast Regional Water Supply Plan (SFWMD 2000).

Natural System Model

The Natural System Model (NSM) is based on the SFWMM, using the same mesh or grid (2-mile-square cells) as the SFWMM, but represents the hydrologic response of a pre-development Everglades using recent (1965–1990) records of rainfall and other climatic inputs (Perkins and MacVicar, 1991). The NSM simulates hydrological processes of natural land cover and drainage using modern climate. Although rainfall patterns and quantities may have been different in the past, reliable records are not available prior to about 1965. The use of recent historical records of rainfall and other inputs facilitates comparisons between the response of the current managed system and that of the natural system under conditions of identical climatic inputs. In this sense, the NSM can be a useful evaluation tool.

The landscape of present-day south Florida has been greatly affected by land reclamation, flood control and water management activities that have occurred since the early 1900s. The NSM in its current form attempts to simulate the hydrologic system as it would function today without the existence of man's influence. The complex network of canals, structures and levees is removed and replaced with the rivers, creeks and transverse glades that were present prior to the construction of drainage canals. Vegetation and topography used by the NSM are based on pre-drainage conditions. The land cover features simulated by the NSM are static, meaning that the model does not attempt to simulate vegetation succession, a primary feature in other landscape models currently under development (Everglades Landscape Model 1994).

The Natural System Model was designed around 1989 using algorithms of the South Florida Water Management Model (SFWMM), which has been the primary tool for simulating regional hydrology. The Natural System Model was first presented at the Everglades Symposium and was later documented and released as Version 3.4 (Perkins and MacVicar 1991). The South Florida Water Management District (SFWMD) and Everglades National Park staff immediately reviewed this initial-release version and recommended changes that led to the development and release of Version 3.6. In 1993, the SFWMD embarked on a major effort to improve the NSM for use as a tool to evaluate various water supply options for the Lower East Coast Regional Water Supply Plan. This effort led to the development of Version 4.1, which was adopted by a Scientific Working Group associated with the regional water supply plan as the best available tool for simulating hydrologic response of the natural Everglades. Further input from the scientists associated with this group resulted in the release of version 4.2. Version 4.5 was released in 2000 and was used in development of the regional Water Supply Plans. Version 4.6 was completed in 2002 to include an expanded period of record, better topographic information and improved rainfall, evapotranspiration and boundary conditions.

Florida Bay Water Budget

A detailed water budget analysis for Florida Bay was produced by Environmental Consulting and Technology, Inc. (ECT) (2005) and is discussed further in the Hydrologic Analysis Section in Chapter 4. The Bay's water budget has several major components. The major sources of freshwater input to the Bay are rainfall, surface water inflow through creeks and overland water inflow across the wetlands. The major sources of freshwater loss from the Bay are evaporation and exchange with marine waters of the Atlantic Ocean and the Gulf of Mexico. In general, groundwater inflows are thought to be small relative to other components of the wetland water budget (Price 2001, Sutula et al. 2001), and thus groundwater flows were not accounted for directly as part of this investigation. All of the freshwater inflow from wetlands enters through the central and northeast regions of the Bay, therefore inflow from wetlands is a more important source of fresh water for these areas than for Florida Bay as a whole.

Rainfall and evaporation dominate the freshwater budget. The magnitude of inflow from wetlands is typically about 10 percent of the magnitude of rainfall over the whole Bay. The relative importance of inflow doubles to approximately 20 percent in the water budget, when just the central and northeast areas are considered. Changes in the Bay's salinity are driven by the net supply of fresh water (i.e., rainfall plus inflow minus evaporation). Changing the amount and timing of inflow from wetlands can affect the Bay's net supply of fresh water, and thus salinity, but would require large changes in inflow from the wetlands.

The interannual variation in rainfall conditions within the Bay is considerable, and that variation in regional rainfall determines the overall pattern of dry, normal and wet hydrologic conditions. As the largest source of fresh water, rainfall in Florida Bay has a more immediate effect on salinity than does freshwater inflow. Rainfall in Florida Bay for a given year may reflect conditions very different from those in the upstream Everglades during that same year. Under current management practices, water management decisions that affect inflow to Florida Bay from the wetlands are made based on regional rainfall conditions over the Everglades and thus do not necessarily reflect needs of the Bay.

Changes in water management practices over the years have resulted in increased surface water discharge into the Taylor Slough/C-111 basins, beginning around 1980. Surface flows increased by a factor of approximately four relative to rainfall at this time. This is perhaps the most significant change that occurred in Florida Bay's freshwater budget during the 1970–2000 period. Flux estimates compiled for the wetland basins from local direct measurements in the later 1996–2000 period are given in **Figure 14**.

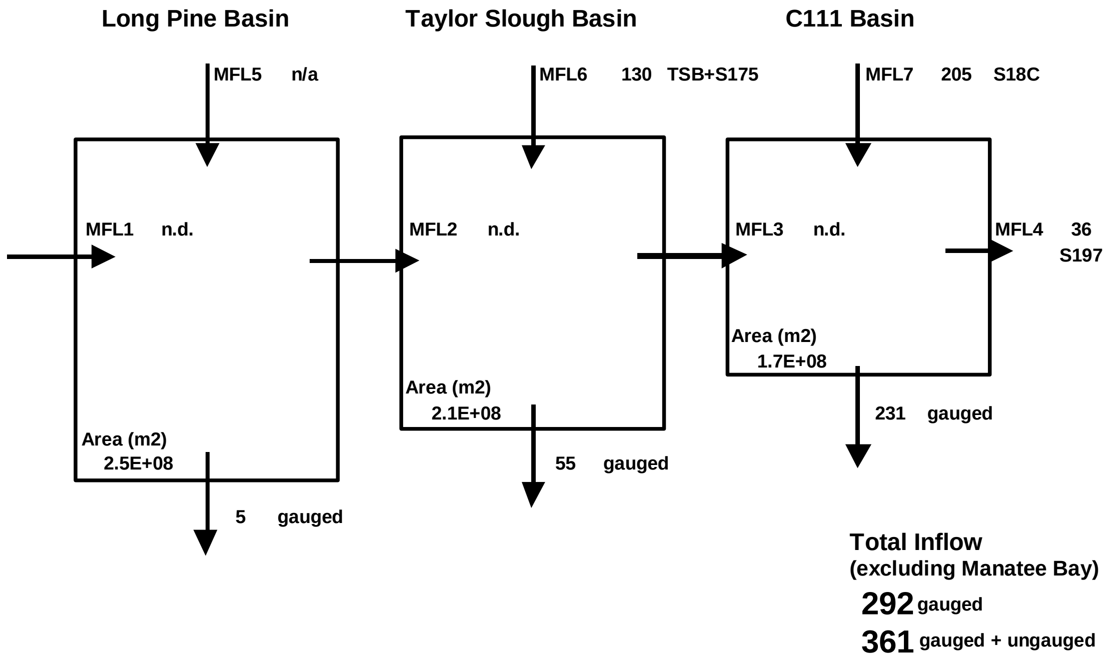


Figure 14. Wetland Water Budget Components for the Period February 1996 through September 2000 as Estimated Directly from Data (fluxes are in units of thousands of acre-feet per year. (Source: ECT Inc. 2005).

SALINITY AND WATER QUALITY RELATIONSHIPS

Florida Bay Salinity Patterns

Salinity is considered a master ecological variable that controls important aspects of estuarine physiology, community structure and food web organization in coastal ecosystems (Myers and Ewel 1990). In Florida Bay, salinity represents the intermediate link connecting the upland water management system to the structure and function of the downstream estuary (Robblee et al. 2001). Estuarine biota existing within these coastal areas has adapted to a broad range of seasonal salinity conditions. Each of these organisms has a range of salinity tolerance and a narrower range of optimal salinity conditions. Motile organisms can leave the area when salinity conditions become unfavorable, but nonmotile species must either tolerate the change or perish (Montague et al. 1989). For a given organism, changing the salinity regime outside of the normal range for too long or too quickly will cause stress to the organism and can result in reduced growth, poor health or even death. Increases or decreases in salinity can also give one species a competitive advantage over another (Livingston 1987). Thus, changes in the water's salinity level or salinity range can be detrimental to some species and favorable to others (Rudnick, 2004). Salinity is perhaps not only the most important physiologically influential parameter for an estuary but also the parameter most likely to change in northeast Florida Bay as a result of changes in water management (Montague et al. 1989). The salinity dynamics of these coastal bays and lagoons in relation to the upstream watershed is a key factor that must be understood in order to establish a minimum flow and level (MFL) for Florida Bay.

Robblee et al. (2001) provide a review of available salinity records for Florida Bay that comprises more than 200 references, including 72 sources of salinity data extending from 1908 to the present. Some data are available prior to 1955; the more usable data for our purposes were collected after 1955. In 1981, Everglades National Park began the first long-term monitoring of salinity within northeastern Florida Bay. This monitoring network was expanded in 1988 to provide increasingly Baywide coverage within the boundary of the park. Since that time, six separate water quality monitoring programs have been funded in South Florida by the South Florida Water Management District (SFWMD), Everglades National Park (ENP) and the Environmental Protection Agency (EPA). The estuarine portion of that program consists of 28 stations located within Florida Bay. Each station was sampled monthly beginning in March 1991 to present day. (For more details see Boyer et al. (1997, 2000) and Boyer and Jones (2003), which discusses Florida International University's Estuarine Water Quality Monitoring Network.) The following discussion relies primarily upon the Boyer and Jones (2003) dataset, which begins in 1989 for some stations and extends to 2002.

Review of salinity records shows that for the past several decades, Florida Bay has generally behaved as a marine lagoon that often experiences hypersaline conditions (more salty than seawater, as a result of evaporation). In addition to direct rainfall, the primary sources of freshwater inflow into the northeast portion of Florida Bay are Taylor Slough and the C-111 Canal; meanwhile, Shark River Slough provides a source of freshwater inflow into the Gulf of Mexico and Florida Shelf waters, affecting salinity within western Florida Bay to some degree during periods of high flow. Along a southwest-northeast gradient, marine influences of the Gulf of Mexico and the Straits of Florida (Atlantic Ocean) decrease from west to east, while in the shallow and confined waters of central and northeastern Florida Bay evapotranspiration can produce hypersaline conditions during dry periods. In contrast, salinity conditions more like those of a typical estuary are found within the coastal lagoons and nearshore areas of northeast Florida Bay, located downstream of Taylor Slough and the C-111 Canal (Robblee et al. 2001).

Available records show that Florida Bay has often experienced hypersaline conditions during years of average or slightly below average rainfall, and extreme hypersaline conditions have been reported within Florida Bay in response to cyclic drought conditions (Robblee et al. 2001). The highest reported salinity for open waters in Florida Bay was 70 psu (practical salinity units) as recorded by Finucane and Dragovitch (1959). Such an event has occurred twice during the period of record (1956 and 1991), near Buoy Key, east of Flamingo (central Florida Bay), near the end of the dry season. During severe drought conditions, salinity have commonly been observed to exceed 40 psu throughout most of Florida Bay, including the Northeastern Coastal embayments, Long Sound, Joe Bay and Little Madeira Bay, which normally receive freshwater inflow from adjacent creeks and upland runoff (Robblee et al. 2001). Since the 1989–1990 period, Florida Bay salinity have declined overall in response to increased rainfall and the influence of active hurricanes and tropical storms experienced during the 1994–1995 period and in 1999. But relatively recent data from the dry seasons since 2000 suggest that Florida Bay salinity may again be on the rise (Lee et al. 2003).

The variability of Florida Bay's average salinity is related to the net flux of fresh water resulting from the combined effect of rainfall into the Bay, freshwater runoff into the Bay and evaporation from the Bay. For the Bay as a whole, both seasonally and annually, evaporation is approximately equal to precipitation, and runoff into the Bay is roughly 10 percent of either (ECT, Inc. 2005). Historical salinity data and salinity proxy (paleoecology) results show that Florida Bay salinity has commonly undergone large changes on time scales of seasonal, interannual, decadal and even longer periods (see section below).

Eastern Florida Bay

Overall, salinity levels are much lower in the eastern Florida Bay than in other parts of the Bay because of eastern Florida Bay's greater proximity to freshwater inflows from the Everglades (Taylor Slough/C-111 basins). Salinity in the basins and creeks that drain into eastern Florida Bay is highly variable on time scales of hours to months. Salinity levels within the small shallow-water bays of eastern Florida Bay can be affected by frontal systems, land-sea breezes and subtropical-storm winds, and southerly winds moving higher-salinity water from Florida Bay into the area's shallow-water bays and creeks can cause wide variations in salinity within relatively short periods (Smith 2001).

Because of its proximity to Taylor Slough and the C-111 Canal, eastern Florida Bay behaves more like a typical estuary in that it has a quasi-longitudinal salinity gradient caused by the mixing of freshwater runoff with seawater (Boyer and Jones 2003). Depending on the season and the dryness or wetness of the year, portions of northeastern Florida Bay can be entirely fresh water or hypersaline (Boyer et al. 1997). Robblee et al. (2001) report that in the vicinity of Long Sound, Joe Bay and Little Madeira Bay, located immediately downstream of Taylor Slough and the C-111 Canal, the mean monthly salinity average about 20 psu ± 11.7 psu. The range of seasonal salinity change within these nearshore areas of northeastern Florida Bay is extreme, with reported mean monthly salinity ranging from near zero psu up to 57.6 psu over the period of record. In contrast, mean monthly salinity in the vicinity of Duck Key, immediately downstream of Joe Bay within Florida Bay proper, averaged about 33 ± 9.4 psu with a period range of 13 to 51 psu. The largest range of salinity variability occurs within eastern Florida Bay and declines toward western Florida Bay. Water management operations upstream within the C-111 basin have also played a role in influencing salinity levels within northeastern Florida Bay. Increased flows through the C-111 Canal because of upstream operational requirements lowered salinity across the Bay during a period of below-average rainfall in south Florida during the 1983–1985 period. But salinity variation stemming from water management in Florida Bay is probably small when compared with natural sources of salinity variation (such as rainfall and evapotranspiration) (Robblee et al. 2001).

Boyer and Jones (2003) provide a summary of water quality trends for 28 monitoring stations located in Florida Bay for the 1991–2002 period of record. The authors spatially analyzed five water quality parameters, including salinity, chlorophyll α, total P, DIN, and turbidity and organized these data into three general groups of stations called "zones of similar influence" representing eastern, central and western Florida Bay (**Figure 15**).

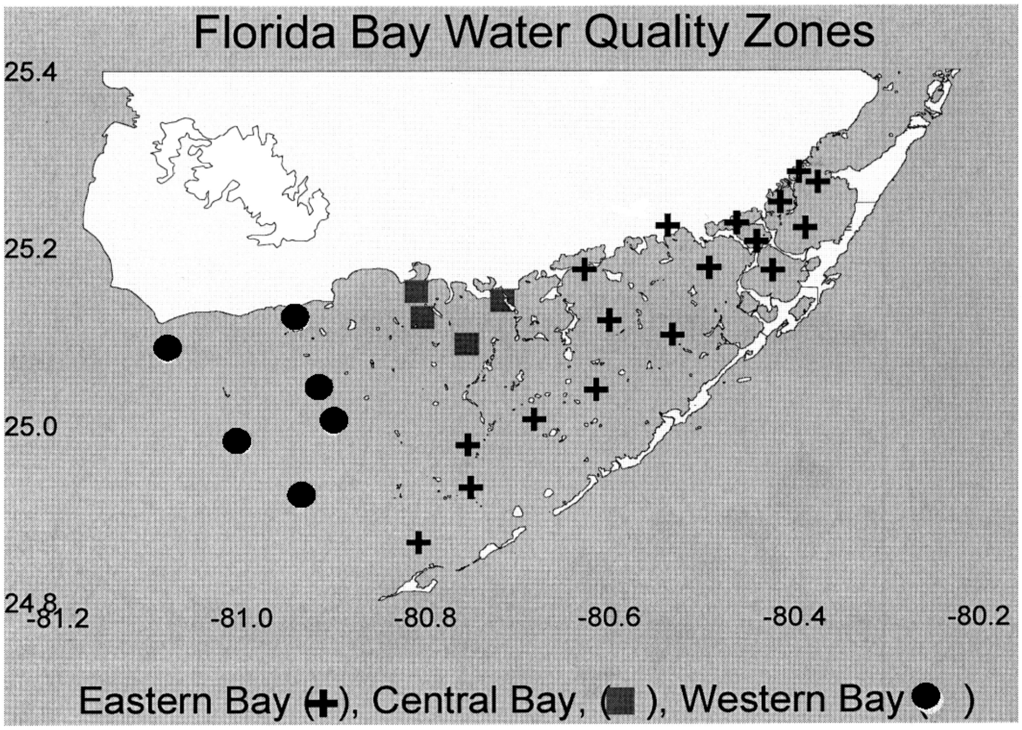


Figure 15. Zones of Similar Water Quality in Florida Bay (Boyer and Jones 2003).

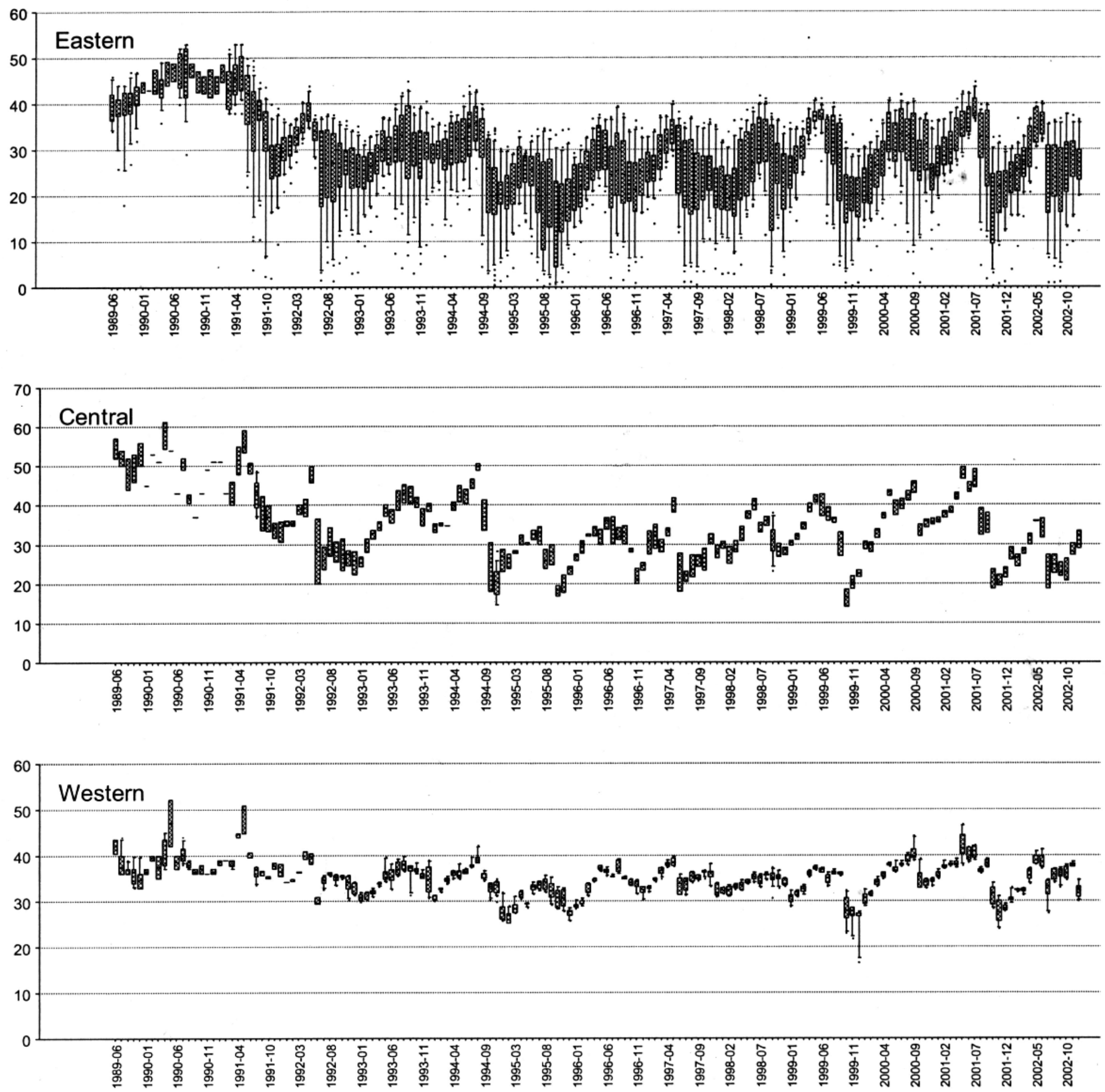


Figure 16. Monthly Median and Range of Salinity (psu) in Three Florida Bay Zones (Boyer and Jones 2003).

In **Figure 16**, the end of the box represents 25th and 75 th percentiles (quartiles), the end of each line (whisker) represents 90 percent and 10 percent of the data range, and the line in the center of the box represents the median of the monthly data. These results show the high-salinity response of eastern Florida Bay after a major drought period (1989–1990), followed by Baywide reductions in salinity and a return to a more stabilized, regular seasonal cycle in response to increased rainfall and possibly increased freshwater inflows from the Everglades (Boyer and Jones 2003). The most obvious trend noted is the wide range of salinity values within eastern Florida Bay as compared with central and western Florida Bay stations. Eastern Florida Bay receives pulses of freshwater runoff from Taylor Slough and the C-111 basin and therefore acts more like a typical estuary with wide ranges of salinity occurring during wet and dry periods.

Central Florida Bay

The broad shallow basins of central Florida Bay are partially isolated from eastern and western Florida Bay because of numerous shallow mud banks. Winds and tides do move some marine water from western Florida Bay across the shallow mud banks and shallow channels into central Florida Bay. And in times of high rainfall, some freshwater runoff can enter central Florida Bay from small creeks and bays along its northern boundary region. But by and large, central Florida Bay is an area of restricted water circulation, low freshwater inputs and long water residence times and is typically hypersaline (salinity > 35 psu) (Boyer and Jones 2001, Smith 2001).

During the summer and early fall, evaporation is thought to dominate the water budget of this area, resulting in hypersaline conditions (Smith 2001, Nuttle 2001). Hypersaline conditions within Florida Bay typically appear first within this central region and are most persistent in the vicinity of Whipray Basin, where mean monthly salinity during summer and early fall averaged about 42 psu ± 8.9 psu (range = 21.2 psu to 57.3 psu) (Robblee et al. 2001). During this period, salinity in Whipray Basin also reached or exceeded 40 psu for almost 60 percent of months when data were available.

Figure 17 is an isohaline map of Florida Bay made from monthly results from a network of water quality monitoring stations from June 1989 to August 1990 (Fourqurean et al. 1993).

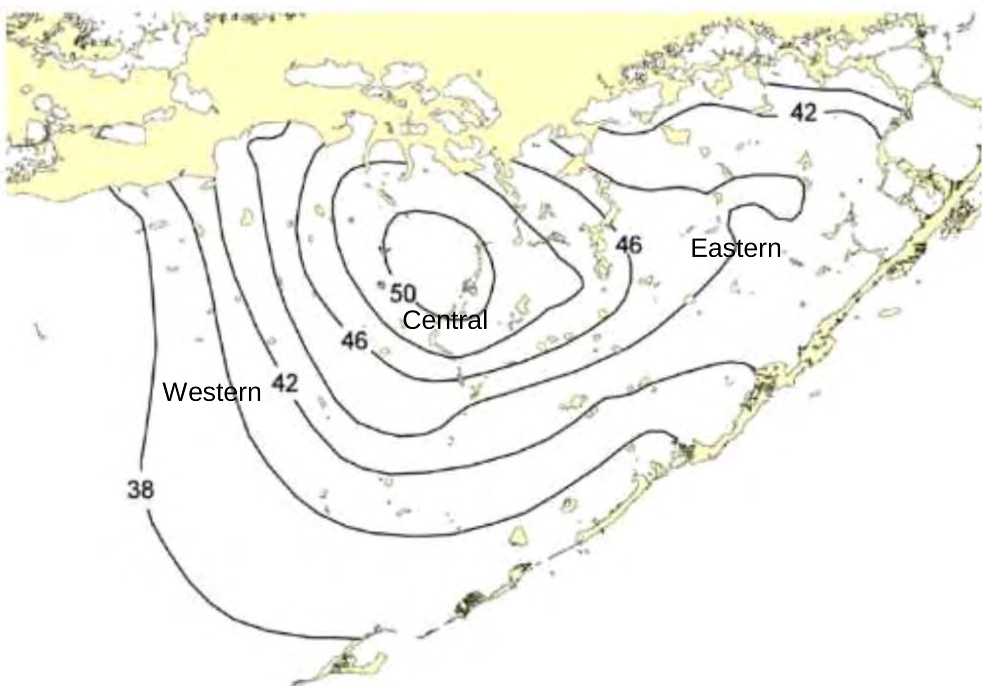


Figure 17. Distribution of Average Salinity Levels within Florida Bay from June 1989 to August 1990 (from Fourqurean *et al.* 1993).

The 1989-1990 period was very dry, with mean salinity exceeding 36 psu for all Bay locations. Highest salinity occurred in the north-central region of the Bay (Rankin Lake). Typically, highest salinity levels (>50 psu) first occur within the central area of Florida Bay and gradually spread toward the northeastern, southern and western portions of the Bay. The occurrence of estuarine conditions (salinity less than 35 psu) across central Florida Bay is rare and usually is associated with high rainfall events such as tropical waves, tropical depressions and hurricanes or with extreme wet periods such as those experienced during 1994 and 1995. These trends are visible in **Figure 16**, in which the central Florida Bay stations exhibit a much narrower range of salinity variability than do the eastern stations (Boyer and Jones 2003).

Western Florida Bay

Tidal variation in western Florida Bay is much greater than in the central and eastern areas, and salinity in the western Bay regions is influenced primarily by the exchange of marine water from the Gulf of Mexico as well as from the Atlantic Ocean through numerous channels cut through the upper and middle Florida Keys. Freshwater inputs from the mainland can also influence salinity there, especially during wet years or as a result of major storm events (Smith 2001), and discharges of fresh water from Gulf Coast rivers have the potential to lower salinity levels of Florida Shelf water moving past western Florida Bay toward the Keys (Smith 2001).

Robblee et al. (2001) reported that near-constant marine conditions predominate in the western portion of Florida Bay. In the vicinity of Long Key, located along the southern boundary of Florida Bay, mean monthly salinity average about 36 psu ± 2.0 psu. Further north, near Johnson Key, located south of Flamingo and sheltered by extensive shallow-water mud banks, mean monthly salinity average about 36 psu,± 5.5 psu. The range of monthly average salinity observed over the period of record was 28.7 to 40.2 psu in the Long Key area and 20.0 to 53.2 psu in the Johnson Key area (Boyer and Jones 2003).

Northern Florida Bay's Coastal Lagoons

The mangrove creeks, swamps and coastal lagoons of the northern portions of Florida Bay are dependent on freshwater inputs from upstream Everglades marshes. Freshwater flow, water levels, salinity, tides and sea level are the major factors controlling this estuarine environment. The coastal lagoon systems most affected by surface water inputs and upstream water management are those located immediately downstream of Taylor Slough and the C-111 Canal, including (from east to west) Long Sound, Joe Bay and Little Madeira Bay. Coastal lakes and lagoons located farther west (such as Madeira Bay, Terrapin Bay, Rankin Bight and Garfield Bight) receive less overland flow and therefore tend to exhibit higher salinity.

Table 3 provides a summary of 1991–2002 salinity data for Long Sound, Joe Bay and Little Madeira Bay (eastern Bay; see **Figure 6**), and for Terrapin Bay and Garfield Bight (along the north central Bay coast). Salinity tends to be lower and have wider ranges at the three eastern stations than at the north-central stations.

Table 3. Salinity Statistics 1991–2002 for Florida Bay Coastal Water Quality Monitoring Stations collected by the FIU (Florida International University) Southeast Environmental Research Center's water quality monitoring program).

Area	Station No.	Salinity (psu)			
		Median: 50^{th} Percentile	25^{th} and 75^{th} Percentiles	10^{th} and 90^{th} Percentiles	Min/Max
Long Sound	8	17.3	10.05 / 24.0	5.6 / 29.7	1.8 / 47.0
Joe Bay	10	9.6	3.2 / 19.7	1.0 / 27.7	0.2 / 54.3
Little Madeira Bay	11	21.3	16.1 / 25.5	13.6 / 32.0	8.4 / 53.0
Terrapin Bay	12	31.2	26.1 / 37.8	21.4 / 43.0	12.1 / 56.0
Garfield Bight	14	32.3	26.7 / 37.0	21.5 / 42.5	12.0 / 63.0

Estuarine organisms that live within the three eastern Bays tolerate a very wide range of salinity conditions ranging from near zero up to 47–54 psu. The eastern Bays' lower overall salinity and temporal variation in salinity occur in response to freshwater inflows received from Taylor Slough and the C-111 Canal. The two western Bays (Terrapin Bay and Garfield Bight) experience less freshwater inflow, have higher average salinity and less temporal variations.

Everglades-Florida Bay Transition Zone

The Everglades-Florida Bay Transition Zone is located upstream from the coastal lagoons. Water enters this zone as discharge from upstream wetlands such as Taylor Slough, local runoff from surrounding wetlands, rainfall and perhaps some amount of groundwater inflow. Under natural conditions, these waters moved in the form of sheet flow across marl-forming sawgrass wetlands and through scrub mangrove forests and saline marshes, eventually discharging into 20 mangrove-lined creeks that empty into Long Sound, Joe Bay, Little Madeira Bay, Madeira Bay and Terrapin Bay. Hydrologic conditions in this area are influenced by sheet flow and seepage of fresh water from the Everglades and by the intrusion of Florida Bay water driven by wind and, to a lesser degree, by astronomical tide, and is isolated from influence by the marine waters of the Atlantic and Gulf of Mexico. Salinity in this zone is fresh to oligohaline throughout much of the year, but salinity can increase, sometimes to hypersaline conditions, during prolonged dry periods. Salinity responds very rapidly to rainfall and inflow from estuarine creeks in the mangrove swamp. High flow causes dramatic freshening in the transition zone. Subsequently, fresh water from these wetlands mixes with more saline Florida Bay waters in the coastal embayments over a period of days to weeks (Marshall et al. 2004).

The range of salinity measured at monitoring stations in this region varies widely (Marshall et al. 2004). At downstream stations near the coastal embayments, salinity varies seasonally between 0 psu and 35-55 psu, while at other upstream locations, the salinity remains at 0 psu for longer periods (roughly six months in the case of Highway Creek and Taylor River) and generally rises to 20-30 psu in the dry season. At most locations the transition from high salinity values to low salinity values is more rapid ("flashy") than the transition from low to high salinity values. (Marshall et al. 2004).

The salinity regime in the transition zone is sensitive to water control operational policies, specifically those governing the working of the L-31W/C-111 canal system discharging fresh water into lower Taylor Slough and wetlands areas south of the C-111 Canal. The lack of tidal passes and the more or less continuous head of fresh water in the upstream wetlands generally prevents the mixing in of water from Florida Bay in this zone, contributing to the creation of extended periods of high or low salinity (McIvor et al. 1994).

Paleoecological Record

Numerous paleoecological studies have been undertaken within Florida Bay in the last decade and have recently been synthesized by the Florida Bay Science Program (Brewster-Wingard et al. 2003). The natural records preserved in the sediments and corals within Florida Bay have yielded valuable historical data. This paleoecological evidence has permitted the delineation of historical trends for both salinity and seagrass. Sediment cores analyzed to date encompass a broad area within Florida Bay, including Joe Bay, Taylor Creek, Pass Key, Russell Bank, Park Key, Bob Allen, Whipray, Rankin, Jimmy Key, Oyster Bay and Coot Bay. Corals have been analyzed from Lignumvitae Basin, Blackwater Sound, Arsenicker Keys, Rabbit Key, Bob Allen Key Basin, Duck Key Basin and Manatee Key.

The majority of the paleoecological work has focused on reconstructing historic patterns of salinity and influx of fresh water into Florida Bay. Results of this work indicate that salinity in

Florida Bay is more strongly correlated to rainfall than to any other single factor (Brewster-Wingard et al. 2003) and that anthropogenic influence plays a secondary role in determining salinity basinwide. Paleoecological studies do indicate that anthropogenic influence may be a factor in the magnitude of salinity variation seen in recent times and may act on a local basis to influence salinity patterns (Dwyer and Cronin 2001, Brewster-Wingard and Ishman 1999, Brewster-Wingard et al. 2001).

Paleoecological studies (Brewster-Wingard et al. 2001, Brewster-Wingard and Ishman 1999, Trappe and Brewster-Wingard 2001) were also used to investigate changes in seagrass species composition and densities in Florida Bay (see discussion under Biological Resources section).

Water Quality Trends

Nutrients

The majority of information presented below is summarized from Boyer et al. 1999, Boyer and Jones (2003) and Boyer and Keller (2003). In terms of water quality, Florida Bay can be divided into three distinct areas based on a spatial analysis of water quality data developed by Boyer et al. (1999) and Fourqurean et al. (1993). These three areas, called "zones of similar water quality," were shown earlier (**Figure 15**) and include specific water quality monitoring stations located within the eastern, central and western portions of Florida Bay. Median values of water quality parameters collected from eastern, central and western Florida Bay sites over the period of record 1989–1997 (Boyer et al. 1999) are shown in **Table 4**. The water column in Florida Bay is generally oligotrophic (nutrient poor), and phytoplankton biomass (measured as chlorophyll α) has historically been low throughout the system. Median total phosphorus or TP concentrations were lowest within eastern Florida Bay (0.25 µmol or micromolar), followed by western Florida Bay (0.58 µmol) and central Florida Bay (0.65 µmol) (**Table 4**) All three areas showed no seasonal trend in TP concentrations and little interannual fluctuation (Boyer et al. 1999).

Table 4. Median Values of Water Quality Parameters of Water Collected from Florida Bay "Zones of Similar Influence" for the 1989–1997 Period of Record (Boyer et al. 1999).

Parameters	Eastern Bay	Central Bay	Western Bay
Salinity (psu)	28.10	34.10	35.20
Dissolved oxygen (% sat)	92.20	86.30	88.80
Total phosphorus (TP) (µmol*)	0.25	0.65	0.58
Soluble reactive phosphate (SRP) (µmol)	0.03	0.05	0.03
Total organic nitrogen (TON) (µmol)	46.00	80.80	30.5
Total dissolved inorganic nitrogen (DIN) ($N0_2^-$ + $N0_3^-$ + NH_4^+) (µmol)	4.35	7.68	1.28
Ammonia ($NH_4^{+)}$ (µmol)	3.41	7.27	1.05
Nitrite ($N0_2^-$) (µmol)	0.23	0.15	0.11
Nitrate ($N0_3^-$) (µmol)	0.71	0.26	0.12
Total Nitrogen (TN):TP ratio	184.40*	131.90	55.60
DIN:SRP ratio	152.50	120.70	51.80
Turbidity (NTU)	2.84	8.56	7.18
Chlorophyll α (µg L^{-1})	0.85*	2.34	1.93

*micromolar (concentration) = number of moles of solute per liter of water

Total phosphorus (TP) concentrations during 1989–2002 generally trended lower Baywide since (Boyer and Jones 2003). As with salinity, most of these reductions occurred in the early record. In the eastern Bay, increased terrestrial runoff may be partly responsible for the decrease in TP, because the concentrations from surface water runoff originating within the Everglades (Taylor

Slough/C-111 basins) are at or below ambient levels of the Bay. In contrast, higher TP concentrations in central Florida Bay are thought to stem in part from that area's long water residence times and high evaporation rates (Rudnick et al. 1999). **Figure 18** shows the distribution of average TP concentrations across Florida Bay for the period 1996–1998. Meanwhile, median levels of soluble reactive phosphate (SRP) were very low Baywide, ranging from 0.03 to 0.05 µmol. These values were generally much lower than measured TP concentrations, probably due to biological uptake and chemical scavenging by the carbonate sediments. The SRP levels in the eastern, central and western areas of the Bay showed no coherent seasonal change (Boyer et al. 1999).

With respect to nitrogen, the median nitrite (NO_2^-) level in the eastern Bay (0.23 µmol was almost twice as high as in the central and western Bays, and in the eastern Bay the median nitrate (NO_3^-) concentration (0.71 µmol) was three to six times higher than in the central and western Bay (**Table 4**). In contrast, in the central Bay median ammonia (NH_4^+) concentrations were two to seven times higher than in the western and eastern Bay, with the central Bay also showing very high peaks in NH_4^+ concentration, up to 120 µmol (Boyer et al. 1999); overall, dissolved inorganic nitrogen ($N0_2^-$ + $N0_3^-$ + $NH4^+$) was two to six times higher in central Florida Bay than in the eastern and western Bay. The median concentration of total organic nitrogen (TON) in the central Bay was double that of both the eastern and the western Bay. **Figure 19** provides a summary of average dissolved inorganic nitrogen (DIN) types across Florida Bay from 1991 to 1999.

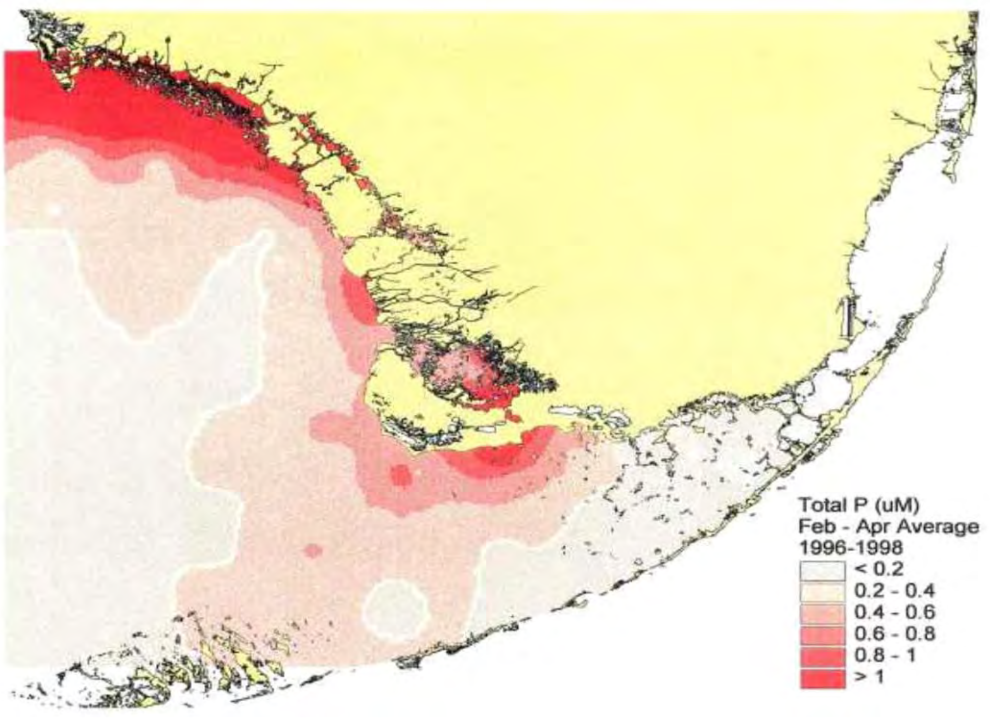


Figure 18. Average Total Phosphorus (TP) Concentrations in Florida Bay, 1996–1998 (Source: Florida International University's Florida Bay Monitoring Program).

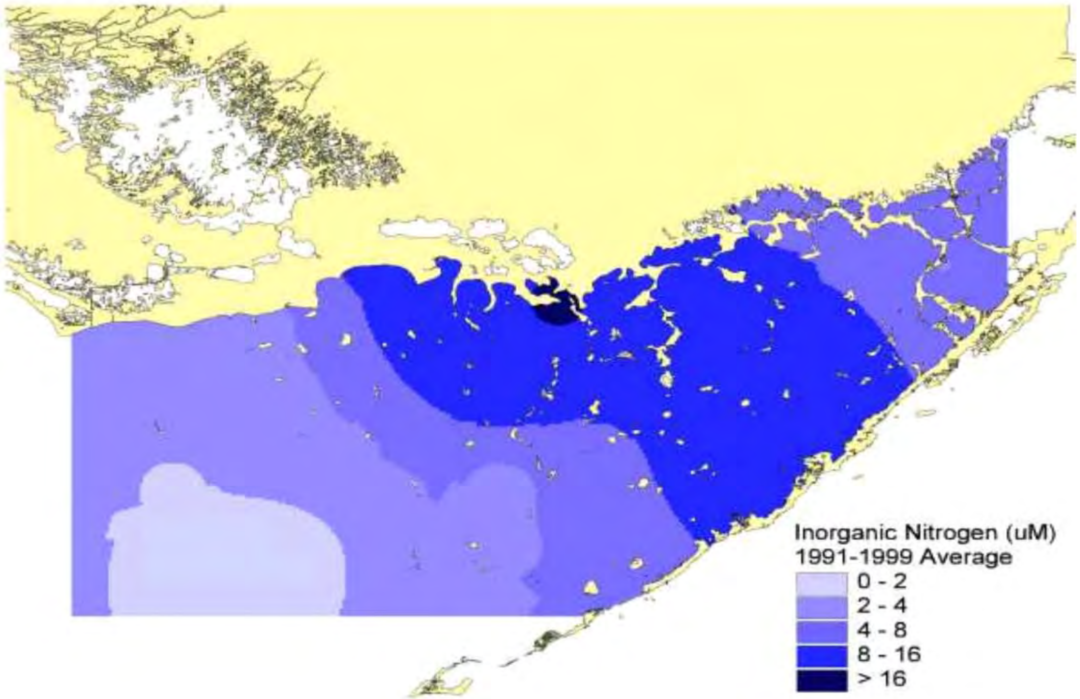


Figure 19. Average Dissolved Inorganic Nitrogen Concentrations in Florida Bay, 1991–1999 (Source: Florida International University's Florida Bay Monitoring Program)

Nitrogen: Phosphorus Ratios

The ratio of total nitrogen to total phosphorus (TN:TP) has been used by many investigators as an indicator of relative N or P limitation for various algal species (Redfield 1958). The TN:TP ratios within Florida Bay exhibit a decrease from east to west (Boyer et al. 1999), meaning that TN is relatively abundant in the east and TP is relatively abundant in the west. The bulk of TN and TP in Florida Bay is in the organic form or in the particulate inorganic form (more refractory and less biologically available forms of nitrogen and phosphorus), but a similar east-to-west decrease in TN:TP ratios has also been observed for inorganic forms of nitrogen (ammonium, nitrate and nitrite) and biologically available forms of phosphorus (phosphate) (Boyer et al. 1999). The primary source of P in all three of these Bay regions is the Gulf of Mexico, while N has many sources (Rudnick et al. 1999). The combined N and P inputs from the freshwater Everglades (Shark Slough, Long Pine, and Taylor Slough /C-111 basins) into Florida Bay as a whole are relatively small—equal to only 11 percent of the N inputs and 3 percent of the P inputs of the Gulf of Mexico to the Bay's western boundary (Rudnick et al. 1999).

In the western and central regions of Florida Bay, the lower N:P ratios relative to eastern Bay values suggest nitrogen limitation of primary production (by algae and aquatic grasses) (Sklar et al. 2002). In contrast, the higher N:P ratios in the eastern Bay suggest phosphorus limitation of primary production (Sklar et al. 2002, Fourqurean et al. 1992). Two contributing factors to P limitation in the eastern Florida Bay are 1) the increased distance from the Gulf of Mexico, which reduces the impact of P inputs from that source, and 2) the removal of P from freshwater sources (such as the C-111 Canal) via biological precipitation of carbonate and co-precipitation of phosphorus (Rudnick et al. 1999).

Turbidity

The lowest median turbidity levels are found in the eastern Bay (2.8 NTU or nephelometric turbidity units), and the highest median turbidity levels are found in the central Bay and western Bay (8.6 NTU and 7.2 NTU). Turbidity exhibited distinct seasonal trends across all of Florida Bay and was generally greatest during the winter-spring months, when wind speeds are highest and winds are generally from the northwest, resulting in the resuspension of fine muds from the bottom.

Chlorophyll *a*

Concentrations of chlorophyll *a* (CHL *a*) were used to estimate phytoplankton biomass. Over the annual cycle of wet and dry periods, median CHL *a* concentrations were lowest (0.85 µg L^{-1}) within eastern Florida Bay and highest in the central Bay. The occurrence of low TP concentrations and low chlorophyll *a* levels suggests that phytoplankton communities within eastern Florida Bay are phosphorus limited. In the central and western Bay, phytoplankton can be phosphorous limited (Fourqurean et al. 1993, Phlips and Badylak 1996, Lavrentyev et al. 1998), but availability of other resources (such as light, nitrogen, silicon) also affect plankton productivity and biomass (Lavrentyev et al. 1998).

BIOLOGICAL RESOURCES

The biological resources of Florida Bay and the transition zone comprise a wide variety of plant and animal communities, each existing within its own Bay habitat and each having been identified as playing an important role in maintaining the overall ecological health of the Bay.

Major Plant Communities

Phytoplankton

Phytoplankton are defined as microscopic primary producers that float or swim weakly in fresh or saltwater bodies. Most phytoplankton are too small to be individually seen with the unaided eye, but when present in high numbers they may appear as a discoloration of the water. Phytoplankton serve in the water column as oxygen producers. These organisms also represent the base of the food chain in most marine and freshwater systems. They are primary producers, using energy from the sun in the process of photosynthesis to create their own food as simple organic compounds from inorganic compounds—mostly from carbon, nitrogen and phosphorus (as well as from silica, consumed by the one-celled plants known as diatoms with their characteristic shapely microscopic silica shells).

Historical accounts from the 1950s to the mid-1980s have characterized Florida Bay as having crystal clear water, expansive seagrass beds and mangrove islands. These early descriptions suggest that under natural conditions, phytoplankton populations were not abundant within Florida Bay (Stumpf et al. 1999). In contrast, since the late 1980s dramatic changes have occurred in the Bay's ecology, with the die-off of large areas of seagrass and the appearance of large-scale blooms of cyanobacterial phytoplankton, or "blue-green algae," over broad areas of the Bay. General consensus exists in the scientific community that these recent dramatic changes in the ecology of Florida Bay are indicative of alterations in key environmental conditions there (Hitchcock et al. 2003). The shift in primary producers and the alteration of the photic environment in the Bay have been hypothesized to be exerting major impacts on the Bay's flora and fauna (Boesch et al. 1993, Fourqurean and Robblee 1999, Rudnick et al. 2005).

Systematic water quality monitoring of Florida Bay has been under way since 1991. The first quantitative indications of major increases in phytoplankton densities in the interior regions of the Bay came from chlorophyll α data collected by Florida International University investigators who made occasional measurements from 1998 until systematic monitoring began (Boyer et al. 1997, 1999). Results indicated a significant step increase in chlorophyll levels in the 1991–1992 period. The increase in algal biomass within the Bay was corroborated by incidental observations by individuals frequenting the Bay for other research and recreation activities. In 1993 the monitoring efforts of FIU were joined by those of a separate research group from the University of Florida that revealed high concentrations of cyanobacteria in the central portion of Florida Bay (Phlips and Badylak 1996, Phlips et al. 1999). In 1994 the phytoplankton research efforts were further expanded to include the Florida Marine Research Institute. All three research teams observed large cyanobacteria blooms in the central regions of the Bay, particularly in the summer and fall (Phlips et al. 1999, Steidinger et al. 2001). During the same period, algal bloom events were also recorded in the western region of the Bay, where the blooms were not typically dominated by cyanobacteria but rather by diatoms (Phlips and Badylak 1996, Phlips et al. 1999, Steidinger et al. 2001); recent efforts by researchers from the University of Miami focusing on the western Bay have provided further support for the importance of diatom blooms in the western region. In general terms, research to date indicates that from the standpoint of algal blooms and species composition, Florida Bay can be divided into three ecologically distinct regions—the northeastern, the central and the western regions.

Northeast Florida Bay's algal populations are characterized by a mixed community of diatoms, cyanobacteria (blue-green algae), dinoflagellates and other microflagellates. The northeast Florida Bay algal community is relatively sparse, characterized by low chlorophyll α concentrations. Phytoplankton blooms do not typically occur here, at least in part as a result of the low phosphorus levels that typify surface water inputs into northeast Florida Bay (Hitchcock et al. 2003).

Central Florida Bay, in contrast, has experienced persistent phytoplankton blooms, most frequently during the summer and fall months. Algal blooms within central Florida Bay originate to the north and during summer (Rankin Bay) and are often displaced to the south (Whipray Basin) in the autumn by wind-driven circulation. In this region phytoplankton blooms consist predominantly of *Synechococcus elongatus*, a picoplanktonic (very small) cyanobacterium that appears to have superior abilities to tolerate a wide range of salinity and can outcompete other algae for low levels of biologically available phosphorus (Phlips et al. 1989, Phlips and Badylak 1996, Hitchcock et al. 2003). The development of recurring and persistent Synechococcus elongatus blooms and high chlorophyll α levels within central Florida Bay is thought to be the result of increased nutrient availability stemming from several factors associated with the decrease in the abundance of seagrass (*Thalassia testudinum*). These factors include the release of nutrients from decomposing seagrass material, the release of nutrient-rich sediment pore water (the water filling the spaces between grains of sediment) resulting from increased sediment resuspension, and an increase in nutrients from terrestrial or groundwater sources (Hitchcock et al. 2003, Fourqurean et al. 1993). Phytoplankton blooms in the central Bay may be linked also to changing nitrogen supply via changing freshwater flow (Brand 2002). Blooms may be sustained in this region by the influx of phosphorus from the Gulf of Mexico and nitrogen from eastern Florida Bay.

In the western region of Florida Bay phytoplankton blooms also occur, but these blooms are composed primarily of two diatom genera, *Rhizosolenia* and *Chaetoceros*. Diatom bloom conditions may be stimulated in the western Bay by high nitrogen and silica content supplied from riverine inputs, mainly from Shark River Slough, and from the increasing proportion of Gulf of Mexico waters (Hitchcock et al. 2003). The growths of diatom-dominated blooms in western

Florida Bay appear to respond favorably to the availability of nitrogen, either singly or in combination with phosphorus and/or silicon. Temperature, salinity and light do not appear to be important factors in the initiation or maintenance of these diatom blooms. Farther west within Florida Shelf waters, diatom blooms appear to be associated with outflows from Shark River Slough. These blooms occur in concert with increased river flow and low-salinity plumes that occur in the vicinity of Cape Sable (Hitchcock et al. 2003). (For additional information on the general characteristics of Florida Bay phytoplankton communities, see Boyer et al. 1997, 1999; Phlips and Badyak 1996; Phlips et al. 1999, 2002; Steidinger et al. 2001; Jurado 2003 and Hitchcock et al. 2003 .)

Seagrasses and Benthic Algae

The area of Florida Bay located within Everglades National Park (ENP) includes approximately 2,000 km^2 of seagrass, dominated largely by turtle grass (Thalassia testudinum) (Zieman et al. 1989). Within outer Florida Bay in water depths greater than two meters, an additional 2,900 km^2 of seagrass beds are estimated to exist, consisting of a mixture of turtle grass, manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*) and paddle grass (*Halophila decipiens*) (Iverson and Bittaker 1986, from diver surveys). Other important seagrass species present within Florida Bay include widgeon grass *(Ruppia maritima*) and star grass (*Halophila englemanni*). Historically, however, turtle grass has been recorded as the dominant seagrass in Florida Bay (Zieman et al. 1989, Tabb and Manning 1961, Fourqurean et al. 2002).

Seagrass beds are a key component of Florida Bay's estuarine environment, providing critical habitat and feeding areas for various commercially and economically important species of fish and invertebrates (pink shrimp, stone crab, spiny lobster) and serving also as feeding grounds for a variety of wading and diving birds (Davis and Dodrill 1989, Thayer and Chester 1989, Fourqurean et al. 2002, Durako et al. 2003). Various listed endangered species such as bald eagles, manatees, crocodiles and sea turtles depend in part on these seagrass communities (Holmquist et al. 1989a, Mazzotti 1989, Boesch et al. 1993). Seagrass communities provide sediment stabilization and improved water clarity by trapping suspended sediments, and they help to absorb inorganic nutrients that enter the estuary from the upstream watershed. Mixed in with the seagrass meadows are several macroalgae species common in Florida Bay, including both drift and attached forms such as *Laurencia* spp., *Batophora oerstedii*, *Penicillus* spp. and *Acetabularia crenulata* (Zieman et al. 1984).

Seagrass Salinity Tolerance, Distribution and Abundance

In terms of seagrass salinity tolerance, *Halodule wrightii* (shoal grass) appears to tolerate salinity fluctuations best, *Thalassia testudinum* (turtle grass) has intermediate tolerance and *Syringodium filiforme* (manatee grass) is the least tolerant (McMillan and Moesby 1967 as cited in Fourqurean et al. 2002). Because of the wide salinity fluctuations (0–40 psu) and long periods of freshwater conditions found within extreme northeast Florida Bay, only one species, *Ruppia maritima* (widgeon grass), was found to flourish there. In contrast, *Halophila* species were generally restricted to areas that were truly marine, with a nearly constant salinity regime (Fourqurean et al. 2002)

Zeiman et al. (1984) used the distribution, standing crop and productivity of seagrass and macroalgae communities to define seven distinct regions of Florida Bay, as follows: 1) northeast, 2) east central, 3) interior (central Bay, north of Atlantic region), 4) Atlantic (central Bay, south of interior region), 5) Gulf (western Bay), 6) mainland (adjacent to south Florida coast from central to western coast/Gulf boundary) and 7) Conchie Channel (a narrow region between mainland and Gulf regions).

In terms of distribution and biomass, turtle grass (*Thalassia testudinum*) is the most abundant seagrass species in Florida Bay, and its distribution and biomass appeared to be associated with sediment thickness. The lowest turtle grass biomass values occurred in areas of thin sediment (ca <1 m), such as shallow basin sediments of the northeast, east central, Atlantic and Conchie Channel regions of Florida Bay. Moderate values of leaf biomass (30–60 g /m^2 dry weight) were found where sediments were thicker (ca 1–1.5 m), such as on top of banks in the northeast and interior regions, basins in the interior region, localized areas in the east central basin and in the shallow, commonly turbid mainland region. Highest values of leaf biomass (75–125 g /m^2 dry weight) were found in areas of thickest sediment layer (>1.5 m) throughout the Gulf region and in denser, lush beds (400 g /m^2 dry weight leaf biomass) on firm banks in the Atlantic region.

Shoal grass (*Halodule wrightii*) was also present but constituted only a minor component of the community (ca 1 g/m^2 dry weight leaf biomass) relative to *Thalassia testudinum*, except for recently disturbed areas in the northeast, east central, interior, Gulf and Conchie Channel regions (Zieman et al. 1989). Only in the mainland region, where terrestrial impacts were greatest, was *Halodule wrightii* found in dense, nearly monotypic stands (ca 90 g/m^2 dry weight leaf biomass). *Syringodium filiforme* (manatee grass) was reported only in deeper waters (ca 3 m) through the Gulf region and at the western end of the mainland region (Zieman et al. 1989).

The distribution of *Thalassia testudinum* communities within Florida Bay has not changed on a Baywide basis since the mid1980s, but a significant reduction has occurred in densities and biomass, based on surveys conducted during the early 1980s and in 1994 (Hall et al. 1999). Baywide, turtle grass densities declined 22 percent between 1984 and 1994, and standing-crop figures declined by 28 percent (Hall et al. 1999). Decreases in standing crop were also observed for *Halodule* (92 percent reduction) and *Syringodium* (88 percent reduction) between surveys. Decreases in standing crop for all three seagrass species were greatest in the western and Gulf of Mexico regions of Florida Bay (Hall et al. 1999).

Major shifts in seagrass species composition have also been reported within Florida Bay over the past two decades (Fourqurean et al. 2003, Durako et al. 2002, Fourqurean and Robblee 1999). For instance, in northeast Florida Bay, *Halodule* has been replaced by *Thalassia* as the dominant seagrass in the Gulf region (west of the Bay boundary). *Thalassia*-dominated communities have changed such that they include more *Syringodium* and *Halophila decipiens*. Alterations in species composition in Florida Bay (especially in the northeast region) caused by changes in freshwater inputs could potentially result in shifts in Florida Bay's food web (Fourqurean and Robblee 1999).

The decline in seagrass abundance observed in the 1994 survey (Hall et al. 1999) followed a well-documented die-off of primarily turtle grass communities central and western Florida Bay that began 1987 and continued through 1990 (Carlson et al. 1990, Robblee et al. 1991b). The clear cause of the seagrass die-off has not been pinpointed, but several contributing factors have been identified (Rudnick et al. 2005, Durako et al. 2003, Fourqurean et al. 2003, Fourqurean and Robblee 1999, Hall et al. 1999, Zieman et al. 1999, Durako and Kuss 1994, Carlson et al. 1990), including long-term reductions in freshwater inputs from the Everglades to Florida Bay as a result of water management practices and persistent drought conditions observed during the late 1980s and early 1990s that caused abnormally high temperatures and extreme hypersaline conditions, increased turbidity and chronic light reduction, increased nutrient availability, hypoxia and sulfide toxicity, and susceptibility to pathogens such as slime mold *(Labyrinthula*).

Seagrass Abundance Based on the Sediment Record

Paleoecological studies were used to investigate changes in seagrass species composition and densities within Florida Bay, based on the abundance through time of the specific animals that feed upon the different underwater vegetation types. These studies used such benthic macroinvertebrates as ostracodes (a group of bivalved crustaceans) and mollusks in the sediment record as indicator species for different types of submersed aquatic vegetation (SAV).

The results indicate declines in diversity and increases in dominance of salinity-tolerant species in several benthic macroinvertebrate groups since the early twentieth century in different areas of the Florida Bay (within the eastern and central basins). Furthermore, during the last 50 years, epiphytal mollusks and ostracods became more abundant throughout the Bay (especially central and western sections), indicating an expansion of dense seagrass occurred. After about 1940, these fauna became relatively abundant throughout the Bay (Brewster-Wingard et al. 2001, Brewster-Wingard and Ishman 1999, Trappe and Brewster-Wingard 2001). These inferences raise the question whether dense and abundant turtle grass beds that were widespread prior to die-off events in the late 1980s reflected a common and natural system state or an anomalous and anthropogenically-driven state (Rudnick et al. 2005).

Vegetation of the Coastal Mangrove Forests and Transition Zone

Mangrove forests within south Florida cover approximately 140,000 ha (345,940 acres), of which about two-thirds exist within the boundaries of Everglades National Park, particularly in the Whitewater Bay/Shark River Slough and along the Gulf of Mexico shoreline. Mangroves are also a key feature of Florida Bay's coastal shoreline and islands. The salinity regime of ENP's eastern mangrove area is influenced by the interplay between fresh water discharged into the area from the mainland and intrusion by salty sea water driven there by wind and tide (Olmstead et al. 1981).

The study area comprises all three species of mangroves—red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*) and black mangrove (*Avicennia germinans*). The study area also comprises all six mangrove community types—overwash, fringe, riverine, basin, hammock, and scrub or dwarf.

- Overwash mangrove forests are found on the smaller islands and fingerlike projections of land within Florida Bay. Overwash mangrove forests generally are dominated by red mangroves. They are overwashed by daily tides, and thus little accumulation of leaf litter occurs there.
- Fringe mangrove forests typically are thin fringes found along waterways, and they may contain all three mangrove species. Fringe mangrove forests occur along protected shorelines and are especially well developed where elevations are higher than mean high tide. Low tidal velocities allow the well-developed mangrove root system to trap sediments. Because of their exposure along shorelines, fringe mangrove forests may be affected by wind, experiencing breakage and accumulation of debris among the roots and trunks.
- Riverine mangrove forests are probably the largest mangrove community type and are found along the major tidal rivers and creeks in the western portion of the Everglades National Park.
- Basin mangrove forests occur in areas in which terrestrial runoff is channeled toward the tidal rivers or coast. Basin mangrove forests are found in depressions and are dominated by white and black mangroves.
- Hammock mangrove forests also occur in areas in which terrestrial runoff is channeled toward the tidal rivers or coast. Hammock mangrove forests are found on slightly elevated areas, and all three mangrove species may be present.
- Scrub or dwarf mangrove forests are found in the limestone substrates within the eastern portion of ENP located upstream of northeastern Florida Bay. The stunted

trees in scrub or dwarf mangrove forests appear nutrient limited and may consist of any of the three mangroves species.

Davis (1940, 1943) provided the first detailed descriptions of the mangrove forests of south Florida. Several of the classic studies on mangrove ecology were performed within the mangrove forests of Whitewater Bay and Shark River Slough drainage basins. Olmstead et al. (1981) used a combination of aerial photography and ground-truthing surveys to map the coastal vegetation from Flamingo to Joe Bay and along a transect through Coot Bay hammock, providing a discussion of the observed effects of hurricanes, fires, freezing, sea level rise, introduced exotics (Brazilian pepper) and human influences.

Odum et al. (1982) provide a discussion of the major values attributed to mangrove forests, including substrate formation, water quality alteration, nutrient cycling, leaf litter production and provision of habitat for fish and other wildlife. The formation of peat soils by mangroves has been studied extensively by geologists in the Florida Bay area (Cohen and Spackman 1972, Cohen and Davies 1989, Gleason 1972).

Mangrove leaf litter sustains an important ecosystem process for south Florida estuaries in that it provides the foundation for a detritus-based food web. In their work on the mangroves in the North River estuary, Odum (1970) and Heald (1969) estimated that litter production by red mangroves averaged 2.4 grams dry weight of organic matter/m^2/day (or 876 g/m^2/year). Riverine, fringe and overwash mangrove communities produced the greatest leaf litter fall. Mangroves export this material as dissolved and particulate organic carbon to adjacent bodies of water, particularly during major storms or hurricanes.

Mangroves are also important as fish and wildlife habitat. Algae, sponges and ascidians attach to the prop roots of red mangroves and provide habitat for amphipods, isopods and algae. Many bird species nest in the canopies of mangrove trees and feed in the surrounding waters. Zieman (1982) emphasizes the importance of the juxtaposition of the two faunally rich habitats—mangroves and sea grasses—present within Florida Bay and the coastal areas of ENP. Individual studies have shown certain species to be dependent on both habitats. For instance, gray snapper, spotted sea trout and red drum recruit into the seagrass habitat but later move into the mangrove habitat for the next several years.

McIvor et al. (1994) summarize the effects of freshwater flow on mangroves and provide examples from Odum et al. (1982) and Hicks and Burns (1975) that suggest that moderate salinity produce optimum conditions for mangrove primary production.

Vegetation of the Tidal Salt Marshes

A curving transitional vegetation area exists roughly between the mangrove forests on the southwest “corner” of Florida and the upstream freshwater marshes to the northeast of these mangrove forests, and it hooks around toward Biscayne Bay. This transitional vegetation area consists of salt prairies and tidal salt marshes. Egler (1952) originally referred to the tidal salt marsh area of south Florida (including the part along Biscayne Bay) as the “southeast saline Everglades.” More recently, Ross et al. (2002) have termed this area the “white zone” because of its appearance as a white band on black-and-white or color infrared satellite photos of south Florida (**Figure 20**). This vegetation area reaches a maximum width of about 15 miles in the area of Shark River Slough and tapers to the east and west (Craighead 1971).

Extensive salt marshes are generally found upland of the mangrove and salt prairies, particularly between major estuaries and in association with open ponds and black mangroves (*Avicennia germinans*) (Craighead 1971). Large areas of rush (*Juncus*) marsh dotted with numerous ponds exist along the interior margins of the Buttonwood Embankment and Cape Sable (Schomer and

Drew 1982). Davis (1940) and Russell et al. (1980) describe these areas influenced by salt water as consisting of dwarf or stunted red mangroves (*Rhizophora mangle*), needle rush (*Juncus roemerianus*), saltwort (*Batis maritima*) and glasswort (*Salicornia perennis*), with some cord grass (*Spartina* spp.). The vegetation composition of this area is related to several factors: soil salinity,

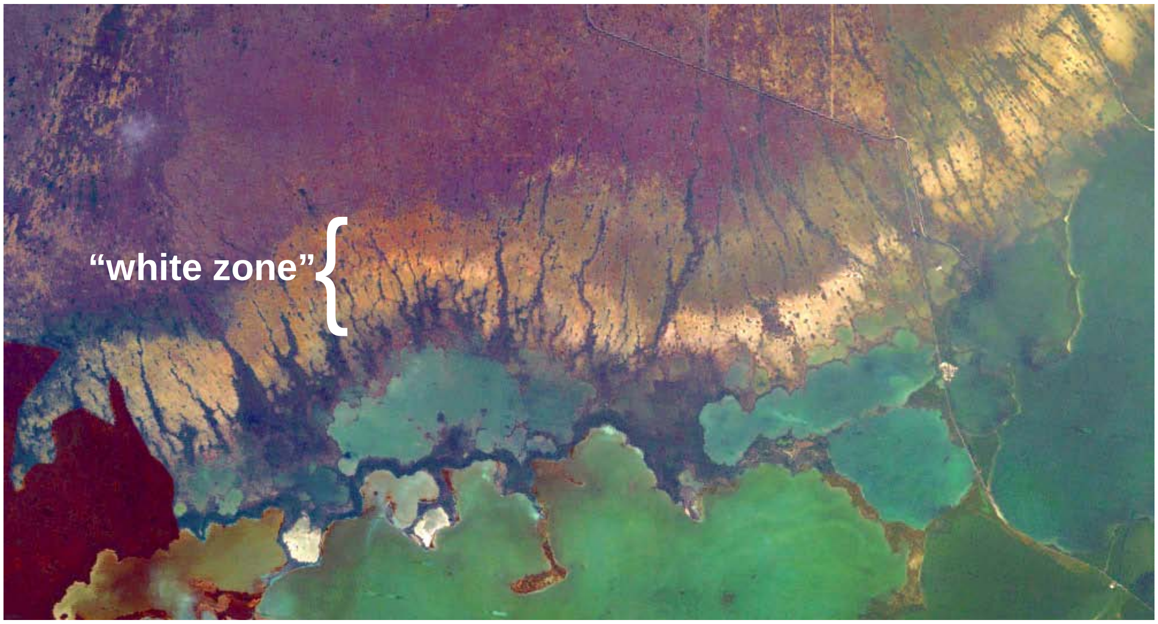


Figure 20. Colorized Infrared Satellite Image of Northeastern Florida Bay, Showing the "White Zone" of Vegetation Located Upstream of the Mangrove Communities.

local topography, historical rates of sea level rise, amount of surface water inflow and frequency of fire. Among these, soil salinity appears to be the major determinant of vegetation type (SFWMD 1992). Many wading birds depend on this transitional area and move among marine, estuarine and freshwater foraging habitats, depending on water levels (Bancroft et al. 1994).

This area of ENP is irregularly influenced by tides (such as the spring tides), and much of it has been exposed in the past to saltwater encroachment as the result of hurricane events. Salinity in these areas ranges from freshwater conditions in the upland marshes during the rainy season to hypersaline conditions during extreme droughts. Russell et al. (1980) mapped the distribution of vegetation in the saline area between Flamingo and Joe Bay. Olmstead et al. (1981) described the complex floristic composition of the saline community.

Ross et al. (2000) examined historical aerial photos (1940 and 1994) of this area for evidence of changes in the position of the "white zone" that might be associated with either sea level rise and/or water management changes. Results showed that the inner boundary of the "white zone" had shifted inland by an average of 1.5 km over the 54-year period, with maximum changes recorded in areas (such as Turkey Point) cut off from upstream water sources by roads or canals.

The timing and volume of fresh water delivered to these salt marshes have been altered by the diversion of water away from Taylor Slough and Shark River Slough and the impounding of water upstream within the Everglades Water Conservation Areas (Light and Dineen 1994). McIvor et al. (1994) suggests that these hydrologic alterations have caused Florida Bay to become more saline in more locations and for longer periods. These changes in freshwater flow have also been associated with decreases in food resource abundance and availability for wading birds in the salt marsh transition areas (Bancroft et al. 1994).

Freshwater-Saltwater Transition

The Everglades-Florida Bay transition zone is an ecotone containing numerous creeks, ponds, lakes, and wetlands that include mangrove swamps and saline marshes. This transition zone is a major component of the greater Everglades ecosystem. This zone is discussed in greater detail in Chapter 4, as a critical resource that needs to be protected by minimum flow criteria. In particular, the mangrove communities within this ecotone historically supported large wading bird and water fowl populations (Lorenz, 1999) by providing a food base in the ponds and marshes and rookeries in the mangrove forests. This zone is of special importance because it is the home of most remaining American crocodiles (an endangered species) in the U.S. (Mazzotti 1999).

Geomorphology and the salinity gradient that exists across the transition zone, from the Everglades to the Bay, are primary factors that structure the ecological communities within the transition zone. Hydrologic conditions across the transition zone are influenced by sheet flow and seepage of fresh water from the Everglades and the intrusion of Florida Bay water, as driven by wind and, to a lesser degree, by astronomical tides. Along the northeast and north-central Florida Bay coast, water exchange between the Bay and the transition zone occurs in creeks that cut through a low-lying coastal ridge.

Wetlands at the boundary of the Bay, and bordering numerous mangrove creeks and ponds within about five kilometers of the Bay, are dominated by *Rhizophora mangle* (red mangrove) trees. Adjacent, interior saline wetlands are also dominated by red mangroves, but these mangroves are dwarfed and in the form of shrubs due to nutrient limitation (Koch and Snedaker 1997). Toward the interior of the transition zone, marshes contain a mixture of mangrove shrubs and graminoid vegetation (mostly *Eleocharis* spp. and *Cladium jamaicense*). Much of this zone has low productivity and sparse vegetation and appears as an area of high reflectance in satellite images (the “white zone” sensu Ross et al. 2000). *C. jamaicense* (sawgrass) dominates the freshwater boundary of the transition zone.

The ponds and creeks of the transition zone form an extensive network of interconnected water bodies that provide habitat and food sources for fishes, invertebrates and nesting wading birds (Lorenz 1999). Submersed aquatic vegetation (SAV) and macroalgae in transition zone ponds and creeks is important as a base of the food web and as habitat. Only a small number of vascular plant and macroalgal species are adapted to grow in the wide ranging and rapidly changing salinity conditions of the transition zone. Most freshwater plants cannot survive salinity exposure, particularly above mesohaline levels. Likewise, most true seagrasses cannot survive sustained (several months) of fresh conditions that are common in the transition zone. If salinity exceeds the tolerance of those species that are adapted to this zone, loss of SAV can occur.

Submersed vegetation in the ponds and channels of the Florida Bay transition zone has not been well studied, except in localized areas (Montague et al. 1998, Morrison and Bean 1997, Tabb and Manning 1961, Tabb et al. 1962, Zieman 1982). Species composition and distribution have not been mapped comprehensively across the northern coast of Florida Bay. However, available data shows that the vegetation of the transition zone is dominated by macroalgae common in fresh water and brackish water (particularly *Chara* sp.) and the vascular plants, *Utricularia* sp. and *Ruppia maritima*. As waters become more saline in the coastal embayment areas of Florida Bay, the vegetation communities become dominated by other seagrass species, *Halodule wrightii* and *Thalassia testudinum*. The SAV community in the transition zone provides an important feeding area for wintering waterfowl such as coot, scaup, widgeon and pintail (Kushlan et al. 1982).SAV in the transition zone serves many ecologic functions for a variety of organisms. Leaves and stems provide substratum and refuge for various plant and animal species. The rhizome and root system stabilize the sediment, transport oxygen from the leaves and oxygenate the sediment in the vicinity of the roots.

Specific studies regarding the epifaunal assemblages within the northeastern Everglades–Florida Bay transition zone are very limited, but Montague et al. (1989) conducted studies that indicated the importance of epifauna associated with the leaves and stems of submersed vegetation within this area. These researchers found a strong correlation of vegetation and benthic infauna in the ponds of the northeastern transitional zone. The most important ecological role of these plants may be the contribution of decomposed plant material, in the form of fine particles suitable for suspension and incorporation, into the detrital food chain (Verhoeven and van Vierssen 1978, Zieman et al. 1984, Kantrud 1991).

Ruppia maritima is a dominant component of the transition zone SAV community and has a well-defined ecologic niche. It grows poorly in water with low water clarity or anaerobic sediments, but it has specialized features enabling survival under a wide range of salinity and high temperatures beyond those tolerated by most other submersed angiosperms (Kantrud 1991). Field observations by Duffy and Baltz (1998) and Castillo-Rivera et al. (2002) suggest that *Ruppia maritima* may provide important habitat to small forage fishes inhabiting lower-salinity areas (Garcia and Vierira 1997, Duffy and Baltz 1998, Castillo-Rivera et al. (2002, 2005). Moreover, Rutherford et al. (1986) demonstrated higher densities of juvenile snook in areas of western ENP estuaries dominated by *Chara* sp., *Ruppia maritima*, and other low-salinity vegetation.

Major Animal Communities

The variety of habitats found in Florida Bay is reflected in the diversity of the Bay's fauna. The system is renowned for its recreational fishery, bird rookeries and populations of endangered and threatened species and species of special concern. Faunal communities of the Bay are often described with reference to four major habitat types—1) hard bottom, 2) soft bottom (mud), 3) submersed aquatic vegetation (SAV) and 4) mangroves and as dominant bottom cover. The range of many Bay species extends beyond the Bay proper into surrounding open-water areas of the Gulf and Atlantic as well as into Everglades National Park, where freshwater marshes transition into mangrove-dominated creeks, ponds and wetlands.

Invertebrates

Found in all of Florida Bay's habitats, invertebrates are a critical link in the system's food web. They range in size from microscopic zooplankton to macroinvertebrates representing several phyla, including Porifera, Cnidaria, Annelida, Mollusca, Arthropoda, Bryozoa, and Echinodermata.

Hard-bottom areas occur throughout Florida Bay and generally receive low inputs of organic matter, have low productivity and thus have low invertebrate diversity relative to other habitat types and adjacent reef communities. Sessile (permanently attached, unable to move about) invertebrate organisms such as sponges and octocorals provide th*e major "structure" to these habitats. Stony coral invertebrate species (genera Siderastrea and Solenastrea*) may also be found in isolated patches. Hard-bottom habitat serves as the primary nursery grounds for spiny lobster (*Panulirus argus*) in Florida Bay, especially in the southwestern part of the system, south of the major mud banks. Lobsters rely on the structure of hard-bottom areas at various stages of their life history—post-larval settlement typically occurs in hard-bottom areas containing the red macroalga, *Laurencia* spp., while juvenile lobsters use large loggerhead sponges and vase sponges for shelter. South Florida, and hence Florida Bay, is a major contributor to the state's lobster fishery, with an average annual 8 million pound harvest by commercial and recreational fishermen.

Mud or soft-bottom communities occupy extensive areas in central and western zones of the Bay (**Figure 9**) and consist of very fine-grained sediments. These communities are generally devoid of submersed aquatic vegetation and attached algae or invertebrates The predominant organisms are invertebrates that crawl across the bottom or burrow beneath the surface, and some benthic fish like the toadfish, *Opsanus beta*. Organisms that live in these areas include polychaete worms, mollusks (clams and snails), tunicates, nematodes, crabs, shrimp, amphipods and echinoderms, including starfish, sand dollars and sea cucumbers.

Dense mangrove and seagrass habitats, in contrast, support more diverse arrays of invertebrate species. Mangrove areas are particularly rich in organic matter, material that is consumed by detritivorous and filter-feeding invertebrates including tunicates, barnacles, bryozoans, tree oysters and polychaetes. Feeding generalists such as jellyfish, isopods, amphipods, gastropods (nudibranchs and snails), crabs and anemones are also common along the mangrove roots and sediments (Kaplan 1988). Many of these same organisms can be found in seagrass-dominated habitats. Gastropods such as the queen conch as well as several echinoderms such as starfish, sea cucumbers and sea urchins feed on organisms within the sediments (Florida Museum of Natural History as cited in Kaplan 1988). Like mangrove roots, seagrass blades provide an important structural component for their inhabitants. Smaller invertebrates live within the epiphytic community on the actual seagrass blades. Other organisms such as juvenile pink shrimp (*Penaeus duorarum*) rely on the blades for refuge from predators; as nursery grounds for pink shrimp, seagrass beds in Florida Bay play an important role in supporting the multi-million dollar Tortugas pink shrimp fishery (Browder et al. 2002).

The emergent plants, SAV and macroalgae of the ponds and creeks within the transition zone provide substrate for faunal epibionts such as bryozoans and hydroids, and also may provide temporary substratum for juvenile anemones and bivalves and the larvae and pupae of aquatic insects (Verhoeven and van Vierssen 1978, Verhoeven 1980a, Boström and Bonsdorf 2000). Other organisms use these plants as habitat and shelter from predation. Small invertebrates are preyed on by mysids, shrimp and forage fish that utilize this habitat (Tyler-Walters 2001). Epifauna, small shallow infauna and larger infauna are probably the most common foods for fish (Montague et al. 1989). Specific studies regarding the epifaunal assemblages within the northeastern Everglades–Florida Bay transition zone are very limited, but Montague et al. (1989) conducted studies that indicated the importance of epifauna associated with the leaves and stems of submersed vegetation within this area. These researchers found a strong correlation of vegetation and benthic infauna in the ponds of the northeastern transitional zone. They could not definitively state, however, whether this correlation was related to the enhanced presence of food and cover that the SAV provide or related independently to the salinity variation causing low densities of both SAV and benthic infauna.

Fish

A wide variety of fish species can be found in all Florida Bay habitats, where they play integral roles in both benthic (bottom) and pelagic (water column) food webs. Most Florida Bay fish species are carnivorous, although some, such as mullet, are omnivorous. They consume prey appropriate to their respective size class. Nearly all but the smallest fish species are both prey and predator during some stage of their life history. Several species spawn offshore and migrate to lower-salinity areas as sub-adults. Tabb and Roessler (1989) listed 167 species of fish for Florida Bay, and is likely an underestimate based on surveys that have since been performed. Florida Bay and its extensive seagrass communities represent an important nursery ground for many species of juvenile fish and invertebrates whose adult forms occur, spawn and are harvested offshore (Browder and Moore 1981, McIvor et al. 1994). Florida Bay also serves as a nursery ground for at least 22 species of commercially and recreationally harvested species (**Table 5**).

The largest fishes in Florida Bay are members of the class Chondrichthyes, the cartilaginous fishes; these top level predators include sharks (such as nurse, bonnethead and lemon) and rays. Florida Bay is also an important habitat for the one federally listed endangered elasomobranch (a subclass of the cartilaginous fishes)—namely, the smalltooth sawfish (*Pristis pectinata*), which is found nearshore and near mud banks, especially over mud and sand bottom. Historical accounts suggest that the smalltooth sawfish was at one time common in Florida (Poulakis and Seitz 2004). Because of their unique morphology, sawfish are vulnerable to net entanglement. It is thought that by catch and habitat degradation, in concert with slow maturation, has caused the decline in smalltooth sawfish abundance over the last century (National Marine Fisheries Service 2000, Poulakis and Seitz 2004).

Table 5. Commercially and Recreationally Important Aquatic Fauna Using Florida Bay as a Nursery Ground (after McIvor e*t al.* 1994).

Scientific Name	Common Name
FISHES	
Family: Sciaenidae (Drums, Croakers)	
Cynoscion nebulosus	Spotted sea trout
Cynoscion arenarius	Sand trout
Bairdiella chrysura	Silver perch
Leiostomus xanthurus	Spot croaker
Menticirrhus americanus	Southern kingfish
Menticirrhus saxatilis	Northern kingfish
Sciaenops ocellatus	Red drum (redfish)
Family: Sparidae (Porgies)	
Lagodon rhomboides	Pinfish
Archosargus probatocephalus	Sheepshead
Family: Haemulidae (Grunts)	
Haemulon sciurus	Bluestriped grunt
Family: Lutjanidae (Snappers)	
Lutjanus griseus	Gray snapper
Lutjanus synagris	Lane snapper
Family: Elopidae (Tarpons)	
Megalops atlanticus	Tarpon
Elops saurus	Ladyfish
Family: Centropomidae (Snook)	
Centropomus undecimalis	Common snook
Family: Sphyraenidae (Barracuda)	
Sphyraena barracuda	Great barracuda
Family: Carcharhinidae (Requiem sharks)	
Carcharhinus leucas	Bull shark
Family: Mugilidae (Mullets)	
Mugil cephalus	Striped (black) mullet
Mugil curema	White mullet
CRUSTACEANS	
Penaeus duorarum	Pink shrimp
Panulirus argus	Florida lobster
Menippe mercenaria	Stone crab

Florida Bay is one of the state's most valued recreational fisheries (commercial harvest has been prohibited in ENP since 1985). In 1989, the economic impact of Florida Bay's recreational fishing industry was more than $7 million (Tilmant 1989), a value that has certainly increased over time. Popular game fish species inhabitants include ladyfish (*Elops saurus*), tarpon (*Megalops atlanticus*), bonefish (*Albula vulpes*), common snook (*Centropomus undecimalis*),goliath grouper (*Epinephelus itajara*), crevalle jack (*Caranx hippos*), gray (mangrove) snapper (*Lutjanus griseus*), sheepshead (*Archosargus probatocephalus*), spotted sea trout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellatus*), great barracuda (*Sphyraena barracuda*) and Spanish mackerel (*Scomberomorus maculatus*). Spotted sea trout is thought to be the only one of these species that spends its entire life span within the Bay (Rutherford 1989).

As long-lived higher-trophic level predators, adults of all game species are subject to bioaccumulating hazardous materials that travel through the Everglades. The Florida Department of Health has issued a health advisory urging limits on consumption of six marine species (snook, spotted sea trout, red drum, permit, wahoo and great barracuda) in Florida Bay and the Florida Keys because of high mercury tissue concentrations.

Smaller species constitute a majority of the fish abundance and biomass in Florida Bay (Schmidt 1979, Thayer and Chester 1989). Forage fish serve a critical link in supporting game fisheries. The following families are broadly represented in Florida Bay: Engraulidae (anchovies), Clupeidae (herrings, menhaden, sardines), Batrachoididae (toadfish), Belonidae (needlefish), Cyprinodontidae (killifish), Poeciliidae (livebearers), Atherinidae (silversides), Syngnathidae (pipefish, seahorse), Gerreidae (mojarras), Sparidae (porgies), Haemulidae (grunts), Mugilidae (mullets) and Gobiidae (gobies).

Tabb and Dubrow (1962), Schmidt (1979), Sogard et al. (1989), Matheson et al. (1999), Ley et al. (1999), Thayer et al. (1999) and Lorenz (1999) describe field surveys highlighting how differences in fish assemblage composition correspond with Florida Bay's physical zonation (the Bay's patterns of water circulation, tidal range and energy, mud bank morphology and distribution, overland freshwater input and salinity regime). Fish community composition also corresponds with regional and local variations in seagrass bed cover and productivity (Johnson et al. 2002a,b). Many forage and sub-adult game species use SAV and mangrove roots as sites of refuge from predation by larger adult fish or avifauna.

Ley et al. (1999) studied of the effects of freshwater flow and salinity on fish communities that inhabit the mangrove prop root habitats of northeastern Florida Bay. Results identified a total of 76 species present, dominated by the families Engraulidae (anchovies), Atherinidae (silversides), Poeciliidae (livebearers) and Cyprinodontidae (killifish).

Table 6 provides a list of the most common forage and transient fish species present within the mangrove prop root area.

Table 6. Common Fishes Found within Mangrove Prop Roots Habitats of Northeastern Florida Bay (Ley *et al*. 1999).

Scientific Name	Common Name
Most Abundant Forage Fish	
Anchoa mitchelli	Bay anchovy
Floridichthys carpio	Goldspotted killifish
Atherinomorus stipes	Hardhead silverside
Poecilia latipinna	Sailfin molly
Lucania parva	Rainwater killifish
Large Transient Species	
Lutjanus griseus	Gray snapper
Haemulon sciurus	Bluestriped grunt
Strongylura notata	Redfin needlefish
Mugil cephalus	Striped mullet
Sphyraena barracuda	Great barracuda

Contrary to expectations, results of this study found that the mangrove habitats of northeastern Florida Bay did not function as a nursery area as generally defined by biologists, in the sense that young-of-the-year juveniles of the predominant transient species were not present within these low-salinity subbasins.

Farther upstream within oligohaline areas transitional between northern Florida Bay and the freshwater Everglades, Lorenz (1999) found representatives from most of these families, as well as freshwater-transient species of cichlids and sunfishes. A total of 39 species dominated by Cyprinodontidae (killifish), Poeciliidae (livebearers), Atherinidae (silversides) and Cichlidae (Mayan cichlid) were reported. **Table 7** lists the most common species of fish recorded in this transitional zone. These small fishes were found to represent an important food source for wading birds (such as roseate spoonbills) and for alligators, crocodiles and other predator species. They were also identified as good bio-indicators for both short-term and long-term impacts to the marsh ecosystem (Lorenz 1999). Work by Duffy and Baltz (1998) and Castillo-Rivera (2002) suggested that *Ruppia maritima* may provide important habitat to many of these taxa.

Table 7. Ten Most Common Euryhaline Fishes Found within the Transition Zone, Northeastern Florida Bay (Lorenz 1999).

Scientific Name	Common Name
Lucania parva	Rainwater killifish
Cyprinodon variegatus	Sheepshead minnow
Cichlasoma urophthalmus	Mayan cichlid
Poecilia latipinna	Sailfin molly
Floridichthys carpio	Goldspotted killifish
Lucania goodei	Bluefin killifish
Fundulus confluentus	Marsh killifish
Microgobius gulosus	Clown goby
Menidia beryllina	Inland silverside
Fundulus grandis	Gulf killifish

Regression analyses indicated that fish density was significantly related to short-term and long-term changes in water level and to long-term variation in temperature. Sites with longer freshwater periods had higher biomass than did sites with shorter freshwater periods. Salinity was determined to be a primary determinant of fish community structure (Lorenz 1999).

Amphibians and Reptiles

Most of Florida Bay's amphibian and reptile species inhabit the mangrove fringe areas rather than the open water. Three amphibian species (all carnivorous) are known to occupy these marginal habitats: giant toads (*Bufo marinus*), squirrel treefrogs (*Hyla squirella*) and Cuban treefrogs (*Osteopilus septentrionalis*). This finding of low species diversity of amphibians in the Bay is thought to stem from the limited abilities of amphibians to osmoregulate in salt water, but also from a lack of detailed surveys in mangrove systems (Florida Museum of Natural History (2004).

Unlike amphibians, members of the Reptilia class are covered in scales or shells, which help protect reptiles' skin from elements such as salt water. This trait has resulted in increased reptilian diversity in mangroves and higher-saline areas. Most of Florida Bay's reptiles are carnivorous. Inhabitant snakes include water snakes (*Nerodia* spp.), rosy rat snake (*Elaphe guttata rosacea*), Florida rough green snake (*Opheodrys aestivus carinatus*), Florida kingsnake (*Lampropeltis getula floridana*), eastern cottonmouth (*Agkistrodon piscivorus*) and the threatened eastern indigo snake (*Drymarchon corais couperi*).

Several turtle species are tolerant of saline conditions in Florida Bay. The diamondback terrapin (*Malaclemys terrapin*) frequents brackish shoreline areas. Each of the four resident sea turtle species is listed by state (Florida Fish and Wildlife Conservation Commission 2004) or federal (United States Fish and Wildlife Service (USFWS) agencies as either threatened (loggerhead sea turtle [*Caretta caretta*]) or endangered (Atlantic hawksbill [*Eretmochelys imbricate]*, Kemp's ridley [*Lepidochelys kempii]* and green sea turtle [*Chelonia myda*s]). The green sea turtle is one of the few Florida Bay reptiles whose diet consists mainly of seagrass and algae. As in other parts of the world, green turtles and loggerheads in Florida Bay have been found with fibropapillomatosis, a disease characterized by tumors on the skin and on the eyes and surrounding tissues that can be fatal in severe cases (Everglades National Park 1997). Scientists continue to study the causes and effects of this disease, as well as distribution and migration of sea turtles to and from the Bay.

Florida Bay is also an important habitat for two resident crocodilian species: the endangered American crocodile (*Crocodylus acutus*) and the threatened American alligator (*Alligator mississippiensis*). The alligator is federally listed because of its morphological similarity to the crocodile, the crocodile being more at risk. Lacking salt glands to assist with osmoregulation, alligators frequent primarily the upstream freshwater margins of Florida Bay. The crocodile population has stabilized in recent years (USFWS 1998), but numbers remain low, leaving the population vulnerable to climatic stressors (hurricanes, cold weather), road mortality and poaching. Unlike alligators, which nest throughout the state, more than two-thirds of Florida's crocodile nests fall within the mangrove shorelines of Florida Bay (Mazzotti 1989, USFWS 1998). For additional habitat protection, areas in northeastern Florida Bay (in and around Little Madeira Bay and Joe Bay) have been designated as a crocodile sanctuary.

Birds

Common in mangroves, shoreline and open-water areas of Florida Bay and in the ponds and creeks of the transition zone, birds are perhaps the most visible fauna in Florida Bay. Representatives of several major bird groups (diving birds, oceanic birds, birds of prey, shorebirds, wading birds and probing birds) can be found there at any time of the year, although many individual species are migratory.

Most avifauna are carnivorous. Those that frequent Florida Bay's mangroves and shorelines eat small invertebrates, fish hiding among mangrove roots or small mammals (in the case of raptors and owls). Piscivorous diving birds such as terns, cormorants and pelicans are regularly seen in open-water parts of the Bay.

Several species nest along Florida Bay's shorelines and on mangrove islands, including osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), magnificent frigatebird (*Fregata magnificens*) and various species of herons, egrets, rails, stilts, ibises, plovers, sandpipers, terns and gulls (Everglades National Park 2004; Kale and Maehr 1990). Several of these species are listed by state and federal agencies as threatened, but the most dependent on the Florida Bay system during their breeding cycle are the endangered wood stork (*Mycteria americana*) and the roseate spoonbill (*Ajaja ajaja*, a species of special concern). Wood stork rookeries have been located in selected areas around ENP, including Cuthbert Lake in the oligohaline central pond area of Florida Bay (Oberhofer and Bass 2003). Currently, 90 percent of the state's spoonbill nests are found on mangrove islands in Florida Bay (Lorenz et al. 2002). Breeding season is very demanding energetically for adult storks and spoonbills because they must frequently leave their nests to forage in adjacent coastal wetlands of the transition zone. Their specialized feeding strategies require prey to be reliably concentrated in these areas. Interruptions to seasonal water drawdown can cause fish to be become dispersed and insufficient, resulting in a reduction of nest success or even in nest failure and abandonment. In recent decades this phenomenon has caused declines in wood stork colonies at Cuthbert Lake and elsewhere as well as declines in spoonbill colonies that nest in northeast Florida Bay and feed in ENP's coastal wetlands (Gawlik 2002, Lorenz et al. 2002).

Mammals

Few mammals are resident in the Florida Bay ecosystem. Certain terrestrial mammals travel into fringing areas of Florida Bay, but few use mangrove wetlands as a preferred habitat. Some animals (such as raccoons) are considered as pests, threatening the survival of other species (such as spoonbills, wood storks and crocodiles) that depend on the system for breeding.

Marine mammals found in Florida Bay are also transient. The endangered West Indian manatee (*Trichechus manatus*) may be found grazing along SAV beds in Florida Bay. In search of warmer, less saline water, dozens of manatees migrate into Florida Bay each winter, presumably from the Atlantic Ocean through cuts in Key Largo (Snow 1991). Manatees have been observed in shallow coastal ponds and bays (such as Joe Bay) adjacent to the southern Everglades. Manatee populations are considerably larger in estuaries along the southwest coast of Florida (Whitewater Bay north through the Ten Thousand Islands), from which they may travel to western parts of Florida Bay. Bottlenose dolphins (*Tursiops truncates*) are the most common mammals in Florida Bay, where they are frequently seen feeding on nearshore schools of fish (Alden et al. 1998). Pilot (short-finned) whales (*Globicephala macrorhynchus*) are also occasionally sighted along the western marine boundary (ENP 1997).

Ecological Relationships and Conceptual Models

Mangrove/ Estuary Transitional Conceptual Model

A conceptual model of a mangrove estuarine transition area has been developed by Davis (2004). This model encompasses a 24-km-long ecotone, spanning the north shoreline of Florida Bay and the Gulf of Mexico—an area characterized by coastal bays and lakes, mangrove and buttonwood forests, salt marshes, tidal creeks and upland hammocks. The external drivers and ecological stressors included in the model are sea level rise, reduction in the flow of fresh water and the introduction of exotic fishes and plants. The ecological attributes chosen as indicators of ecological health are estuarine geomorphology, estuarine fish communities and fisheries, the wood stork and roseate spoonbill, estuarine crocodilian populations and the structure and function of the mangrove forests and associated plant communities. A description of the Mangrove/ Estuary Transitional Conceptual Model (Davis 2004) is provided in **Appendix B**.

Florida Bay Conceptual Model

A conceptual ecological model for Florida Bay has been developed by Rudnick (2004) encompassing the entire complex 850-square-mile array of basins, banks and islands forming Florida Bay. The model considers natural as well as anthropogenic external drivers and ecological stressors. Whether through temporal variability of saline levels or through nontemporal shifts in saline levels, alteration of the salinity regime is a major stressor. Salinity changes can be caused by various factors, including water management practices, flow restrictions caused by construction of railway and highways, sea level rise, and major hurricanes. Additional external stressors in the model include nitrogen and phosphorus inputs, pesticides, mercury and fishing pressure. The ecological indicators in the model are related to the health of the ecosystem and/or are intrinsically important to society, and they include the following: the seagrass community, water quality, mollusks and benthic grazers, pink shrimp, fish populations and birds. A description of the Florida Bay Conceptual Model (2004) is provided in **Appendix B**.

Endangered and Threatened Species

The Florida Bay watershed hosts at least 23 endangered threatened wildlife species, according to recent estimates (see **Table 8**).

Hydrological alteration of south Florida's natural areas through drainage and development has contributed to the decline of a number of species once common to the Everglades and Florida Bay watershed. South Florida's wading bird population, for instance, has experienced a 90 percent decline since the turn of the century. And today, the Florida panther, which was once common throughout the state, but is now primarily restricted to South Florida, including the Everglades and the Florida Bay watershed, is on the verge of extinction.

Legislation such as the Endangered Species Act of 1973 has afforded a measure of protection for Florida's wildlife by mandating the classification of certain wildlife species as "endangered" or "threatened" and by providing for legal protection of species so listed. In detailing the reasoning behind such protection, the act formally cited the aesthetic, educational, historical and scientific value of the various species of fish, wildlife and plants concerned. Beccue (1999) provides a list of endangered and threatened species found within Everglades National Park and Florida Bay (within the boundaries of ENP). An endangered species is defined as a species, subspecies or isolated population that is, or soon may be, in immediate danger of extinction unless the species or its habitat is fully protected and managed for its survival. A threatened species is defined as a species, subspecies or isolated population that is likely to become endangered in the near future unless the species or its habitat is fully protected and managed for its survival (Beccue 1999).

An evaluation of the life histories, habitat and freshwater requirements of the listed species shown in **Table 8** suggests that the American crocodile, the roseate spoonbill and the Florida manatee (a subspecies of West Indian manatee) potentially could be affected by a reduction in flows of fresh water and/or by conditions of increased salinity. These species are discussed in more detail below, based primarily on information from the Multi-Species Recovery Plan (USFWS 1999) and BFA, Inc. (2004).

Table 8. Threatened and Endangered Species Found within the Florida Bay Watershed.

Scientific Name	Common Name	NPS[a]	FFWCC[b]
Mammals			
Trichechus manatus	West Indian manatee	E	E
Felis concolor coryi	Florida panther	E	E
Mustela vision evergladensis	Everglades mink		T
Peromyscus gossypinus	Key Largo cotton mouse	E	E
Neotoma floridana smalli	Key Largo wood rat	E	E
Birds			
Rostrhamus sociabilis plumbeus	Snail (Everglades) kite	E	E
Mycteria americana	Wood stork	E	E
Ammodramus maritima mirabilis	Cape Sable seaside sparrow	E	E
Ammodramus savannarum floridanus	Florida grasshopper sparrow		E
Picoides borealis	Red-cockaded woodpecker	E	T
Haliaetus leucocephalus leucocephalus	Southern bald eagle	T	SSC
Charadrius melodus	Piping plover	T	T
Sterna dougallii	Roseate tern	T	T
Ajaja ajaja	Roseate spoonbill		SSC
Falco peregrinus tundrius	Arctic peregrine falcon	T	E
Reptiles and Amphibians			
Crocodylus acutus	American crocodile	E	E
Alligator mississippiensis	American alligator	T	SSC
Drymarchon corais couperi	Eastern indigo snake	T	T
Eretmochelys imbricata	Atlantic hawksbill turtle	E	E
Chelonia mydas	Green turtle	E	E
Lepidochelys kempii	Atlantic ridley turtle	E	E
Dermochelys coriacea	Atlantic leatherback turtle	E	E
Carretta carretta	Loggerhead turtle	T	T
Invertebrates			
Papilio aristodemus ponceanus	Schaus' swallowtail butterfly	E	E
Orthalicus reses	Stock Island tree snail	T	E
Plants			
Chamaesyce garberi	Garber's spurge	T	

E= endangered, T = threatened, SSC = species of special concern
[a] = from National Park Service (Beccue 1999)
[b] = from Florida Fish and Wildlife Conservation Commission (2004)

American Crocodile

The American crocodile (*Crocodylus acutus*) is protected pursuant to the Florida Wildlife Code and the federal Endangered Species Act, as amended. Crocodiles are designated as *endangered* at both levels. An initial recovery plan for this species was developed in 1979 and updated in 1994, and recovery actions are currently being implemented in accordance with the Multi-Species Recovery Plan for South Florida (USFWS 1999), which states that "the American crocodile is a valuable indicator species of the health of south Florida's estuarine environments." Critical habitat for this species has been designated to include the majority of Florida Bay, the coastal mangrove zone, the C-111 Canal basin, and selected areas to the northeast of US Highway 1 (Turkey Point area).

Crocodiles are large, greenish-gray reptiles that reach lengths of approximately 3.8 m (12.35 ft). Males are somewhat larger than females, and both can be distinguished from alligators by having a longer, narrower, more-tapered snout. Crocodiles are found primarily in mangrove swamps and low-energy, mangrove-lined bays, creeks and inland swamps (Kushlan and Mazzotti 1989). Favored nesting areas include sandy shorelines or raised marl creek banks adjacent to deep water, particularly those protected from wind and wave action (USFWS 1999). During the non-nesting season, crocodiles typically inhabit brackish and freshwater inland swamps, creeks and bays (Kushlan and Mazzotti 1989). American crocodiles favor darkness for foraging, from shortly before sunset to shortly after sunrise. Juveniles typically eat fish, snakes and crabs and other small invertebrates. Adults eat fish, snakes, crabs, turtles, birds and small mammals (Ogden 1978b, Ross and Magnusson 1989).

Together with the American alligator (*Alligator mississippiensis*), the American crocodile is one of two species of crocodilians endemic to the United States. Crocodiles' historic range may have extended up the east coast as far as Lake Worth Lagoon (Palm Beach County), up the west coast to the Tampa Bay area and south to Key West, but crocodiles presently inhabit only coastal areas of extreme south Florida, being found primarily in mangrove communities in Monroe, Miami-Dade, Collier and Lee counties. Their range also includes the Caribbean, Mexico, Central America and northern South America.

The reduction in numbers of these large reptilian carnivores has resulted from, among other things, crocodile hunting and the fragmentation and loss of crocodile habitat stemming from increased urbanization and agricultural lands uses (USFWS 1999). At varying times and locations, crocodile nest failures have been attributed to flooding or desiccation (Mazzotti et al. 1988, Mazzotti 1989). And Ogden (1978a) suggests that the disappearance of crocodiles from much of Florida Bay came about "at least in part" as a result of increased mortality rates among salt-stressed juveniles.

Regarding salinity preferences and tolerances, Dunson (1982) used laboratory studies and field data collected from Florida Bay to document that although American crocodile hatchlings are intolerant of 35 psu water, most small American crocodiles maintained body mass at salinity up to 17 psu, and some even gained mass at 26 psu. Kushlan (1988) suggests that hatchling crocodiles possess a number of behavioral adaptations for survival in hypertonic conditions, including consuming water-laden prey items, avoiding intake of salt water, riding on top of salt water and drinking fresh water from pools and from surface lenses of fresh water after rainfall.

Water salinity affects habitat use and may be locally important, especially during periods of low rainfall. American crocodiles have physiological mechanisms to reduce water loss and they also have salt glands that excrete excess salt, but for juveniles of the species, the maintenance of an osmotic balance requires access to low salinity. Hatchling crocodiles are particularly susceptible to osmoregulatory stress and may need to have brackish to fresh water (4 ppt) available at least once per week to increase growth (Mazzotti et al. 1986). Crocodiles larger than 200 g have sufficient mass to withstand osmoregulatory stress and are not commonly believed to be affected by drought (Mazzotti and Dunson 1984). Crocodiles' needs for fresh water are usually satisfied by frequent rainfall, which results in a lens of fresh water on the surface for several days after a rain (Mazzotti and Dunson (1984). During periods of low rainfall, hatchling crocodiles are probably stressed and some may die. Anthropogenic changes in the amount and timing of the flow of fresh water to south Florida may have resulted in shifts in the distribution of American crocodiles. Estimates suggest that from historical numbers of 1,000 to 2,000, the population of crocodiles in south Florida dropped to all-time lows during the 1960s and 1970s (between 100 and 400 non-hatchlings, according to USFWS 1999), with numbers increasing substantially since that time.

Roseate Spoonbill

The roseate spoonbill (*Ajaia ajaja*) is the only spoonbill species native to the Western Hemisphere. It has been designated by the state of Florida as a species of special concern and is protected pursuant to the federal Migratory Bird Treaty Act but not pursuant to the federal Endangered Species Act. No recovery plan has been developed, and no designated critical habitat exists for this species. Accounts of historical populations suggest that the spoonbill population in the United States numbered in the thousands prior to the 1850s, with a rapid decline setting in from 1850 through 1920. This decline reduced the nationwide population to approximately 25 pairs (Allen 1942) and was attributed to plume hunting, the disturbance of colonies and the collection of nestlings and adults for food. By 1941, only one nesting colony (Bottle Key) was known to exist in Florida (Lorenz et al. 2002). After protection mechanisms were enacted, populations began to rebound, particularly in coastal Texas and Louisiana, and estimates were that by the 1970s there existed some 2,200 to 2,700 nesting individuals.

At present, the primary nesting areas for this species are in extreme south Florida, with several widely spaced individual nesting sites existing in other coastal areas in the southern half of peninsular Florida as well. Some 90 percent of spoonbill nesting in the state has been on mangrove islands in Florida Bay in Everglades National Park, with Lorenz et al. (2002) reporting that in recent years more than 30 islands in the Bay have hosted spoonbill nesting colonies. Cumulatively, the lack of terrestrial predators (primarily raccoons), the minimal amount of human disturbance, the lack of parasites and disease and the presence and availability of prey items all probably contribute to the continued viability of individual Florida Bay nesting sites (Lorenz et al. 2002).

Spoonbills forage in shallow marine, brackish and freshwater sites, including tidal ponds and sloughs, mudflats, mangrove-dominated pools, freshwater sloughs and marshes and manmade impoundments (ENP, 1997; Paul, 2003). Mangrove-dominated shorelines and the marine-estuarine transition area have been documented as the primary foraging areas used by the spoonbills that nest in Florida Bay. Valuable foraging habitat for spoonbills appears to be provided by the dwarf mangrove community present in areas of little soil accumulation overlying rock substrate.

Annual wet season and dry season water level fluctuations typical of south Florida are critical to the nesting success of many wading birds, including spoonbills, whose annual nesting cycle is timed around the decreasing water levels associated with the winter-spring dry season. Foraging by adults is most effective during this period, when the population of prey, which has increased during the wet season, becomes concentrated as surface waters diminish. Recent studies by Lorenz (1999, 2000) reveal, however, that comparatively higher and more variable salinity in the same Florida Bay coastal wetlands have resulted in reduced prey biomass for foraging spoonbills. Long-term studies of spoonbill nesting territories indicate that spoonbills respond to the destruction or degradation of their foraging grounds by relocating closer to suitable grounds. In Florida Bay, two hundred plus breeding pairs nest on Sandy Key, Tern Key, and Joe Key, plus other islands, from November through March. (ENP 1997)

Florida Manatee

The Florida manatee (*Trichechus manatus latirostris*), a subspecies of West Indian manatee, is a large, herbivorous, air-breathing aquatic mammal that can be found within suitable habitat throughout much of peninsular Florida. The Florida manatee is protected pursuant to the Florida Wildlife Code and the federal Endangered Species Act, as amended. Its current designation at both levels is as endangered, although the Florida Fish and Wildlife Conservation Commission (FWC) is considering a downlisting to *threatened*. An initial federal recovery plan for this species was developed in 1996, and the Multi-Species Recovery Plan for South Florida (USFWS 1999) contributed information pertinent to Florida Bay. Critical habitat was designated for this species in the early 1970s as manatee-occupied areas that “have those physical or biological features essential to the conservation of the manatee and/or which may require species management considerations.” In Florida, manatees are commonly found from the Georgia/Florida border south to Biscayne Bay on the east coast and from Wakulla River south to Cape Sable on the west coast (Hartman 1974, Powell and Rathbun 1984). Because of their ability to navigate coastal water control structures, manatees are also found throughout the waterways in the Everglades and in the Florida Keys and even within Lake Okeechobee (USFWS 1999). Temperatures in the Florida Keys are suitable for manatees, but the Keys’ lack of fresh water has produced low manatee population numbers (Beeler and O’Shea 1988). The Multi-Species Recovery Plan does not give specific locations, maps or other descriptions that specifically define critical manatee habitats within Florida Bay, but it is assumed that members of this endangered species potentially inhabit all areas of Florida Bay (at least part of the year), especially areas of luxuriant seagrass beds.

Water temperatures lower than approximately 20° C appear to increase manatees’ susceptibility to cold-related stress and cold-induced mortality. In north and central Florida, manatees’ wintertime distribution is centered near reliable sources of warm water (such as springs and power plant discharges). Other manatees move south, where it is less likely that ambient water temperatures will drop below acceptable levels. Manatees unquestionably inhabit areas with marine salinity and appear to survive equally well in fresh and salt waters, but in areas of primarily marine salinity, manatees are well known for their desire to drink fresh water. They will drink water from hoses and frequently travel upstream into rivers and canals with the purpose, at least in part, of reaching freshwater areas.

Seagrass and mangrove habitats provide foraging, calving, resting and mating areas for manatees, and thus the presence, abundance and distribution of this animal species are indicators of the health and vitality of the area’s seagrass and mangrove habitat systems. In fact, manatees have been identified by USFWS (1999) as an indicator species for aquatic habitats, including seagrasses and mangroves, in the south Florida ecosystem. Because manatees forage primarily on seagrasses and because the presence, distribution and density of individual seagrass communities depend somewhat on salinity factors, manatees could potentially be affected by reductions in flows of fresh water delivered to Florida Bay. Even so, the greatest present threat to manatees within Florida is the high rate of boat-related manatee injuries or deaths. Between 1986 and 1992, watercraft-manatee collisions accounted for 37.3 percent of all manatee deaths in Florida (USFWS 1999).

CHAPTER 3: RESOURCE FUNCTIONS AND CONSIDERATIONS

INTRODUCTION

Section 373.0421 (1)(a), F.S., identifies the types of water resource functions that should be considered for protection from significant harm. A minimum flow and level (MFL) may be used to protect any one of a number of functions, such as navigation, recreation, fish and wildlife, or water quantity/quality. The present chapter briefly reviews the diverse water resource functions of Florida Bay and identifies water resource functions that should be considered in defining significant harm.

The previous chapter provided a general description of this system's natural features, hydrologic conditions, structural alterations and operational protocols. When setting a minimum flow or level, water management districts are required to consider changes and structural alterations that have occurred to a water resource. This chapter looks at the functions of the Bay and the watershed.

WATER RESOURCE FUNCTIONS AND CONSIDERATIONS

Florida Bay

The primary resource function of Florida Bay is its highly productive estuarine habitat for a diverse faunal community. Another important function is recreation.

Freshwater Supply into the Bay

The continued health of Florida Bay depends upon maintenance of brackish estuarine communities along its coastal margins and prevention of excessively high salinity conditions within the Bay itself. Significant amounts of freshwater flow are required in order for desirable salinity concentrations to be sustained. The sources of this fresh water include runoff, direct rainfall, seepage and other means. Inflow into the Bay from the major canals via Taylor Slough is a major source of fresh water during dry periods.

The current analysis is designed to support the development of minimum flow criteria needed to protect existing resources for the Florida Bay area. These criteria will become increasingly important to the Bay with the passage of time, as freshwater resources in the region become further divided among other uses. Setting a MFL criteria while freshwater sources are still available to the area will help ensure that amounts required to protect the Bay's resources from significant harm can be adequately quantified and secured.

Water Quality

Freshwater inflow to Florida Bay may provide an important source of nutrients that supports the primary productivity of this system. This Bay, like other estuaries, depends on a certain minimum input of new nutrients to maintain productivity (Redfield 1958), but short-term limitation of new nutrients associated with period of low flow is unlikely to be harmful. Excess nutrients, however, may be a concern in terms of eutrophication and potential for hypoxic or anoxic conditions associated with organic loading and plankton blooms. Florida Bay is generally considered to be an oligotrophic estuary (Boyer et al. 1997). Nutrient inputs from the Everglades are likely important for the productivity of the Bay, but the extent to which the quantity of this nutrient input is natural or augmented by human activity is uncertain. Phytoplankton blooms, which have been common in the Bay since the early 1990s, may reflect impaired water quality and the influence of excess nutrients from the watershed (Brand 2002, Rudnick et al. 2005). If so, then periods with moderate and large quantity freshwater flow are of greater concern than periods when MFL alternatives may be in effect. Most of this nutrient input is in the form of dissolved organic matter (Rudnick et al. 1999)

Input of dissolved and particulate organic carbon to estuaries can come from terrestrial sources, as well as from primary or secondary production within the estuary. Terrestrial inputs of dissolved and particulate organic carbon to Florida Bay will be affected by minimum flow requirements. For the Bay, organic matter inputs are largely in the form of dissolved compounds, which may affect productivity, dissolved oxygen demand, and nutrient availability. The relative importance of the input of external organic matter and associated nutrients versus internal production and cycling to the production of phytoplankton, benthic algae, and seagrass is uncertain.

A related factor to consider may be the impact of reduced flow on sediments and turbidity. With low freshwater flow and therefore low imported organic matter and nutrients during periods when MFLs may be in effect, the overall loading of organic materials into the Bay would be low and the extent of hypoxic and anoxic conditions minimal. Alternately, reduced flow may promote the accumulation of organic matter (dissolved or particulate) in areas from which such material would otherwise be transported and dispersed farther into the Bay during periods of rapid water movement.

Protection of Fish and Wildlife Habitat

Submersed aquatic vegetation (SAV), macroinvertebrates, birds, shellfish and finfish form prominent components of the Florida Bay ecosystem. SAV in the Bay and the transition zone serve a variety of key functions. They provide habitat for numerous benthic and pelagic organisms such as invertebrates and fishes (Thayer et al. 1984). They increase benthic primary productivity and stabilize sediments (Stoner 1983, Virnstein et al. 1983, Gilmore 1987, Fonseca and Fisher 1986, Woodward-Clyde 1998). They provide food sources for trophically and commercially important organisms (Dawes et al. 1995, Virnstein and Cairns 1986) and can form the basis of detrital food chains (Zieman and Zieman 1989). Seagrasses cover much of the bottom of Florida Bay and provide the foundation for a substantial commercial and recreational fishery in the Bay and neighboring waters, in part by supplying food and habitat for small fishes and invertebrates whose seasonal abundance is critical for successful growth and reproduction of the larger sport fish and commercial species, as well as for birds. Although less studied, SAV are also present in the ponds and creeks of the transition zone and provide similar benefits in terms of habitat, food sources, water quality, and substrate stabilization. Seagrasses and invertebrates are sensitive to changes in water quality (Kemp et al. 1983, Twilley et al. 1985) and are often included in monitoring programs as indicators of estuarine health (Tomasko et al. 1996). Restoration and protection of seagrass, macroinvertebrates, fishes and birds are major goals of the Comprehensive Everglades Restoration Plan.

Recreation

Recreational activities in Florida Bay include boating, fishing and bird watching. MFL criteria are expected to sustain the aquatic communities that provide the landscape, fish and wildlife that support these recreational activities.

Watershed

The immediate watershed into Florida Bay consists of the natural communities of Everglades National Park and the islands of the Florida Keys. A crucial function fulfilled by the watershed and requiring consideration in the development of MFLs is the watershed's ability to supply appropriate quantity and quality of water at the right locations for fish and wildlife habitat in the Bay and for other water resources and resource functions, such as recreational use and environmental enhancement/restoration of other ecosystems. The major competing needs are to manage surface water in adjacent areas for drainage, flood control and water supply.

Water Supply and Flood Control

The primary source of water flow from the regional water management system into Florida Bay is conveyance from the Water Conservation Areas southward through Taylor Slough and the C-111 Canal basin (mostly the southeastern panhandle of Everglades National Park). The amount of water delivered through these areas depends on regional rainfall and water level conditions and on the amount of water diverted to coastal canals to provide recharge to the surficial aquifer. The coastal canals in Miami-Dade County serve three primary functions: 1) to remove excess water from the canals' associated basins, primarily by discharging this water to tide, 2) to supply water needed for maintaining regional groundwater levels during periods of low rainfall and high water demand from agricultural and coastal wellfields and 3) to maintain groundwater table elevations at the coastal structures to prevent saltwater intrusion.

Wetlands

Wetland communities in the Florida Bay watershed offer storage, retention and infiltration sites for surface water flows. Groundwater and surface water are both used in areas adjacent to this watershed to meet potable water supply needs and for irrigation demands for landscape and agricultural crops. As urban and agricultural development continues, the volume, duration and frequency of floodwater flows into Florida Bay may increase. The existing infrastructure of drainage systems was never intended to eliminate flooding altogether in developed areas. Nearby natural and undeveloped regions can serve as locales for storage of excess floodwaters and infiltration of runoff and can function as vehicles for moving floodwaters away from developed areas.

Water Quality

Most of the immediate watershed into Florida Bay is undeveloped and serves as an important source of clean fresh water to the estuary by providing soil stabilization, low pollution loading, reduction of pollutants from runoff, a buffer from urban land uses and maintenance of the oligohaline zone. Urban and agricultural lands farther north and east can be sources of excess nutrients, pollutants and contaminants that may adversely affect downstream resources, especially during periods of high flow.

Protection of Fish and Wildlife Habitat

Maintenance of sufficient water depth within the watershed is needed in order to protect plant and animal communities in wetlands, sloughs and marshes. Freshwater wetlands in the watershed provide habitat for wildlife species important to predatory animals such as wading birds that feed upon those species and important also to recreational fishing and hunting interests. Freshwater fish species found in the Florida Bay watershed's wetlands, sloughs and marshes include largemouth bass, speckled perch, bluegill, shellcracker, redbreast, warmouth sunfish, bowfin, channel catfish, minnows and several exotics, and local game wildlife varieties found there include deer, hogs and ducks. In addition, the freshwater swamp community contains a number of species of trees and shrubs that provide important specialized habitats and food (such as fruits and seeds) to birds—most notably, to migratory and endangered bird species—and other wildlife.

The Florida Fish and Wildlife Conservation Commission's report, "Closing the Gaps in Florida's Wildlife Habitat Conservation System," (Cox et al. 1994) identifies the region as an important area in terms of maintaining several wide-ranging species that make up an important component of wildlife diversity in the state. Furthermore, the southeastern Florida region is a unique place for the concentration of migratory species. Many birds use the area for wintering, breeding, feeding and nesting. In addition, several species of marine fish depend on the estuary as spawning and nursery areas because of its relatively fresher water.

The fresh water from the watershed flows into protected lands and water bodies, including Everglades National Park, Biscayne National Park and the Florida Keys National Marine Sanctuary. These national preserves harbor several protected species (such as the American crocodile and the West Indian manatee, subspecies Florida manatee) that rely on appropriate timing and distribution of freshwater inputs to preserve their habitats.

Recreation

Recreational activities in the Bay and its watershed include boating, birding, diving and fishing. These are considered non-consumptive uses. Identifying the MFLs required in the watershed is necessary in order to provide for adequate access and enjoyable use of the resource. MFLs are also needed to ensure adequate availability of water for plant communities that constitute habitat and landscape, and for wildlife that support these recreational activities.

ALTERATIONS

Hydrologic Changes

During the past century, the hydrology of south Florida underwent a vast series of modifications stemming from agricultural and urban development and the expansion of commercial and recreational activities. The structure and biological resources of Florida Bay and its watershed have been irreversibly altered by changes made to provide drainage and flood protection for cities, homes and farms, to provide water for irrigation and to improve boat access for recreational and commercial use.

Dredging and filling of tidal and freshwater wetlands throughout the watershed have resulted in the alteration of areas critical for the production of fish and wildlife and have reduced the watershed's capacity to store excess fresh water that falls during the rainy season for subsequent slow release to the estuary during dry periods. Loss of shoreline habitat to dredging and filling of coastal waters and wetlands has been relatively limited throughout most of the Bay but nevertheless has resulted in a decline in the tidal marshes and swamps that function as a natural filter to remove sediments, nutrients and pollutants from the water column.

Exchange with the Atlantic Ocean along the eastern side of Florida Bay was hampered by filling for the Florida East Coast Railroad (1912) and then the Overseas Highway (1938), resulting in longer retention times within the Bay and higher salinity and poorer water quality during dry periods. Construction of the water management system's canals, structures and pump stations in the upstream watershed has altered the volume, timing and distribution of freshwater inflows to the Bay.

Hydrologic alterations not only resulted from human activities, such as water management, but also by larger scale changes in sea level. Sea level in south Florida has risen at least 20 cm (7.9 inches) over the past 100 years (Wanless et al. 1994), and this change has certainly affected the salinity regime of Florida Bay and the Everglades watershed (Rudnick et al. 2005). In particular, salt water intrusion of the southern Everglades has expanded the inland boundary of the salinity transition zone and increased the magnitude of salinity in this wetland (Ross et al. 2000).

Water Quality and Biological Changes

Florida Bay historically experienced lower salinity conditions than those prevailing during the twentieth century. According to available evidence (Brewster-Wingard et al. 2003), more fresh water used to enter the system from the Everglades watershed and nutrient loads were likely low as a result of the pristine state of the terrain. Submersed aquatic vegetation, macroinvertebrates, fish, wildlife and birds were abundant.

Hydrologic changes during the past century have altered the quantity, quality, timing and distribution of waters entering the Bay and ultimately the biological conditions in the Bay itself. The estuary has experienced increased loading of nutrients and pollutants, contributing to diminished water clarity, periodic algal and phytoplankton blooms, occasional periods of widespread seagrass mortality, highly varying salinity and increased duration, frequency and extent of hypersalinity. The combination of physical, hydrologic and water quality changes has resulted in periodic large-scale loss or destruction of habitats, especially of seagrass beds and their associated communities. Plant and animal communities in this ecosystem have been affected during these periods of habitat alteration and destruction, with an attendant decline in diversity and abundance of wildlife resources.

SUMMARY AND CONCLUSIONS

The Florida Bay ecosystem has been stressed and altered in the past century by effects of human activities, including the construction and operation of the C&SF project, which have altered the timing, distribution and quantity of fresh water flowing through the Everglades toward Florida Bay. Combined with sea level rise, these changes have altered the salinity regime of the Bay and consequently the ecological structure and function of the Bay (Rudnick et al. 2005). The Bay's resources and functions have been altered by hydrologic modifications. Despite long-term and recent changes of ecosystem structure and function, the Bay remains a productive and, compared to most Florida estuaries, relatively pristine environment with healthy habitat and rich fish and wildlife resources that support recreational activities.

Protections associated with MFL implementation and improvements associated with CERP are expected to sustain and then rehabilitate (restore) the Florida Bay ecosystem and its resource functions. Determination of the lower limit of flows beyond which significant harm would occur to this ecosystem should be linked to the maintenance of appropriate salinity levels for MFL criteria determination. Salinity is a major ecological variable that controls important aspects of estuarine community structures and food webs (Myers and Ewel 1990).

CHAPTER 4: RELATIONSHIPS THAT PROVIDE THE BASIS FOR DEFINING IMPACTS TO WATER RESOURCES

This chapter summarizes technical analyses conducted by the SFWMD Coastal Ecosystem Division to support the development of MFL criteria for Florida Bay. The MFL development process requires several steps, including the following: 1) identifying important resources and functions of Florida Bay, 2) surveying the available information and potential MFL approaches, 3) documenting historic conditions and developing a water budget, 4) determining technical relationships between freshwater inflow and salinity and determining these relationships' impacts on the Bay's resources and functions and 5) developing numeric criteria that reflect the degree of impact that occurs to water resources as a function of freshwater inflow from the upstream watershed.

BACKGROUND AND SCOPE

Florida Bay is a shallow estuary (average depth <1 meter) dominated by a complex array of small islands and mud banks that restrict the internal circulation of water within the Bay. Freshwater inputs into Florida Bay from its feeder watershed area in the Everglades occur largely in the form of overland flow through Taylor Slough, the C-111 Canal basin and numerous small creeks that transverse the mangrove-dominated Everglades–Florida Bay transition zone before reaching the coastal embayments within northeastern Florida Bay. A significant volume of water from the Everglades also flows through Shark Slough to the Gulf of Mexico through Whitewater Bay, which is on the southwest coast of Florida, near the western boundary of Florida Bay, but the present analysis only considers the flows entering northeastern Florida Bay through Taylor Slough and the C-111 Canal system (**Figure 21** and **Figure 22**).

Within the rich history of research and monitoring activities in Florida Bay, no comprehensive analysis of information directly linking the responses of Florida Bay biota to changes in freshwater inflow and/or salinity had yet been compiled as of the outset of the present work effort. Following initial analyses of available information, several studies were carried out specifically to support the present MFL analysis, including various modeling efforts, most notably 1) a mass-balance hydrologic model, 2) a dynamic seagrass model and 3) statistical higher-trophic-level species models. Further model development and refinement will proceed over the next several years in support of CERP's Florida Bay and Florida Keys Feasibility Study, which is evaluating the restoration needs of Florida Bay. These modeling efforts will also provide greater predictive capability for future MFL evaluations. This chapter supports the initial development of MFL criteria for Florida Bay. Its objectives are the following:

- To describe data and methods considered for use in MFL development.
- To analyze hydrology and salinity conditions.
- To analyze specific ecologic consequences of a range of different hydrologic and salinity conditions within the Florida Bay ecosystem.

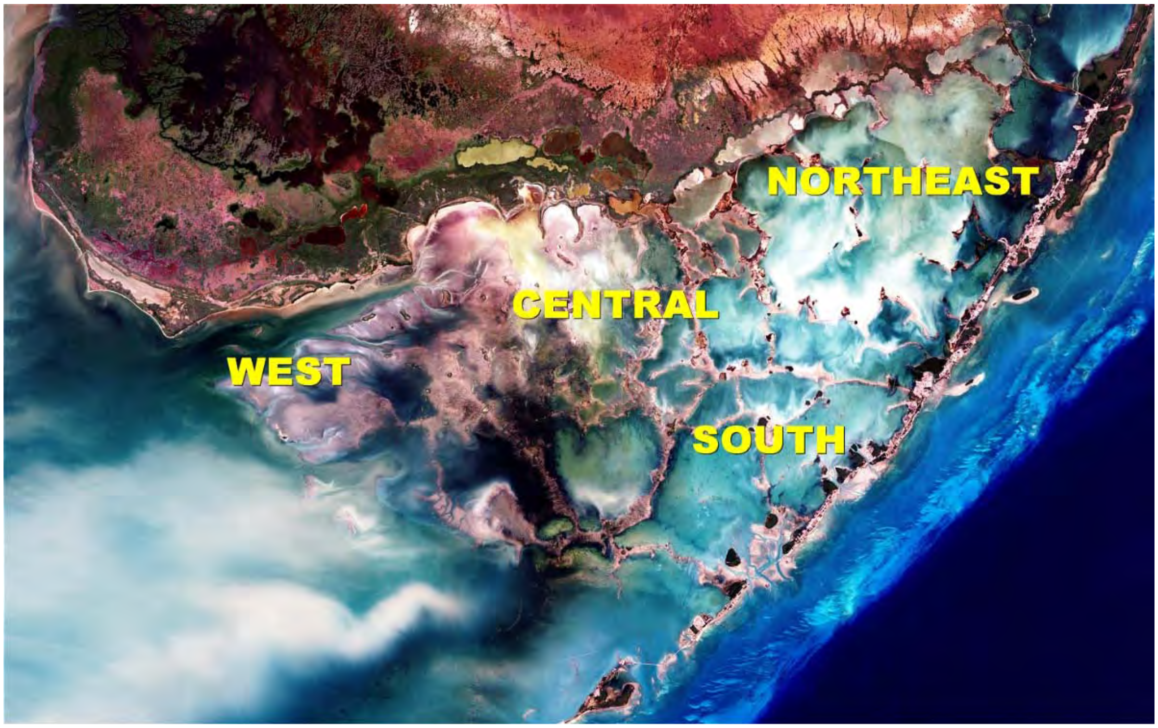


Figure 21. LANDSTAT-7 Extended Thematic Mapper Image of Florida Bay, Showing the Shallow Bank Bathymetry and Four Principal Subregions (from Florida Bay Science Program 2003).

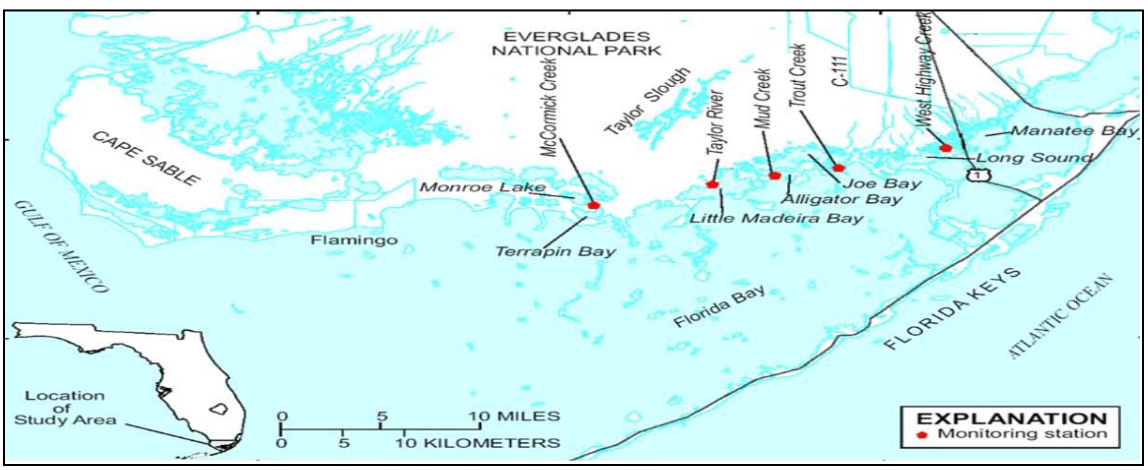


Figure 22. Location of Gauged Inflow to Northeastern and Central Florida Bay (Hittle et al. 2001).

TECHNICAL METHODS AND DATA USED TO DEVELOP FLOW AND WATER LEVEL RELATIONSHIPS FOR THE MFL

Methods Considered

The methods used to determine water level and flow criteria were reviewed and categorized by Alber (2002) within the framework of the following three main areas of effects studied: 1) freshwater inflow effects, 2) estuarine-condition effects and 3) estuarine-resources effects. Freshwater inflow methods consider effects on the estuary that are related directly to quantity, quality or timing of inflow. Estuarine-condition methods contemplate effects on the estuary that are related to inflow characteristics of salinity, sediment or dissolved or particulate material. Estuarine-resources methods examine effects on the estuary related to organism/species composition, abundance, distribution or production in the inflow-affected area.

Within these three broad categories of effects, several possible approaches or methodologies can be considered for use in establishing water level and flow criteria. The following categories of approaches were recently summarized during development of the MFL criteria for the Northwest Fork of the Loxahatchee River (SFWMD 2002):

Instream Flow: There exist at least three general instream flow methodologies: 1) historical-flow techniques rely solely on preexisting data, 2) hydraulic techniques generally relate flow to the hydraulic geometry of a channel and 3) habitat methods relate flow to habitat suitability curves. When applied to estuaries, instream flow methods assume that the flow requirements of tributaries are commensurate with the flow requirements of the estuary. These methods are considered freshwater inflow approaches.

Hydrologic Variability: The hydrologic-variability approach extends instream flow techniques to include a more extensive analysis of flow characteristics. This approach also assumes that the freshwater needs of tributaries are the same as, or commensurate with, those of the estuary. An untested but feasible application of the method would be to use it with salinity data rather than flow data. This is also considered a freshwater inflow approach.

Habitat Overlap: As originally formulated, the habitat overlap approach has three steps: 1) salinity favorable for a particular species or group of species are identified, 2) the location in the estuary of favorable stationary habitat (such as sediment type or SAV) is determined and 3) freshwater inflows that create overlap between desired salinity and stationary habitat are identified. To date, dynamic habitat variables other than salinity have not been considered. This is considered an estuarine-condition approach.

Indicator Species: The indicator species approach relates a change in abundance, distribution or condition of a particular species to flow or salinity. Criteria for selection may include a species' endemism to the locale, its status as a species at risk, its ecologic importance and/or its commercial, recreational or aesthetic value. Statistical methods can be applied as a means to match species abundance values or species condition to appropriately time-lagged inflow or salinity conditions. This is considered an estuarine-resource approach.

Valued Ecosystem Component: An extension of the indicator species approach, analysis based on valued ecosystem components (VEC analysis) accounts for more known or suspected intermediate variables. Recommended by the United States Environmental Protection Agency (1987) for national estuary programs to characterize constraints on living resources, VEC analysis plays an important part in a general model for the design of eutrophication monitoring programs in South Florida estuaries. VEC is a goal-driven approach that has the ability to focus research and to provide managers with short-term alternatives in data-poor estuaries. This is considered as another estuarine-resource approach.

In developing an approach to establish water level and flow criteria in Florida Bay, several sources of information were reviewed, including the following: 1) freshwater flow management methods being used in riverine estuaries nationwide and elsewhere in Florida (Estevez 2000), 2) a special issue of the journal Estuaries dedicated to minimum flows (Estuarine Research Federation 2002), 3) other coastal/estuarine MFLs (Caloosahatchee, Loxahatchee and St. Lucie) established at the District and 4) published literature and reports specific to Florida Bay to help identify potential indicator species or VEC, as well as available sources of hydrologic, physical and historical information.

Proposed Approach

A resource-based approach using the submersed aquatic vegetation (SAV) indicator species *Ruppia maritima* (widgeon grass) in the Everglades–Florida Bay transition zone is proposed for Florida Bay. Impacts to this resource are defined in terms of a freshwater flow regime and corresponding salinity levels required for survival of this SAV habitat. Using a 33-year historical time period 1970–2000, which includes drought conditions and changes in water management in the basin, the inflow to northeastern Florida Bay is determined. During the periods characterizing impacts to resources in the transition zone, concurrent inflow and resulting salinity conditions in northeastern Florida Bay are considered. The inferred effects on the northeastern Florida Bay seagrass community and upper-trophic-level species are described under these low flow conditions to assess the impacts of a low flow on the downstream Florida Bay ecosystem.

A representative gradient traversing the Everglades–Florida Bay transition zone into northeastern Florida Bay is used. This gradient comprises the following three regions:

- Ponds in the Taylor River region of the mangrove-dominated transition zone.
- Little Madeira Bay (a coastal embayment on the northern boundary of Florida Bay).
- A northeastern Florida Bay open-water area (Eagle Key Basin).

The gradient includes SAV and macroalgal communities ranging from 1) freshwater SAV (dominated by *Ruppia maritima*) at the inland ecotone (transition area between two different ecological communities) to 2) mixed seagrasses that are dominated by *Halodule wrightii* (shoal grass) and *Thalassia testudinum* (turtle grass) in the coastal transition zone and Florida Bay (**Figure 23**). The gradient is located in the part of Florida Bay that receives most of the fresh water that flows directly into the Bay from the Everglades, and salinity along this gradient is influenced by water management. This gradient is appropriate for several reasons, including the following:

- The gradient originates in ponds within the Taylor River region's upland ecotone, which represent an environment that typically supports predominately freshwater to brackish-water biota on an annual basis and is highly sensitive to saltwater intrusions.

- The gradient passes through downstream areas that include a representative coastal embayment (Little Madeira Bay)that receives direct freshwater inflow from Taylor Slough. The environment and salinity regime are similar to those of other coastal embayments receiving freshwater inflow, such as Long Sound or Joe Bay.

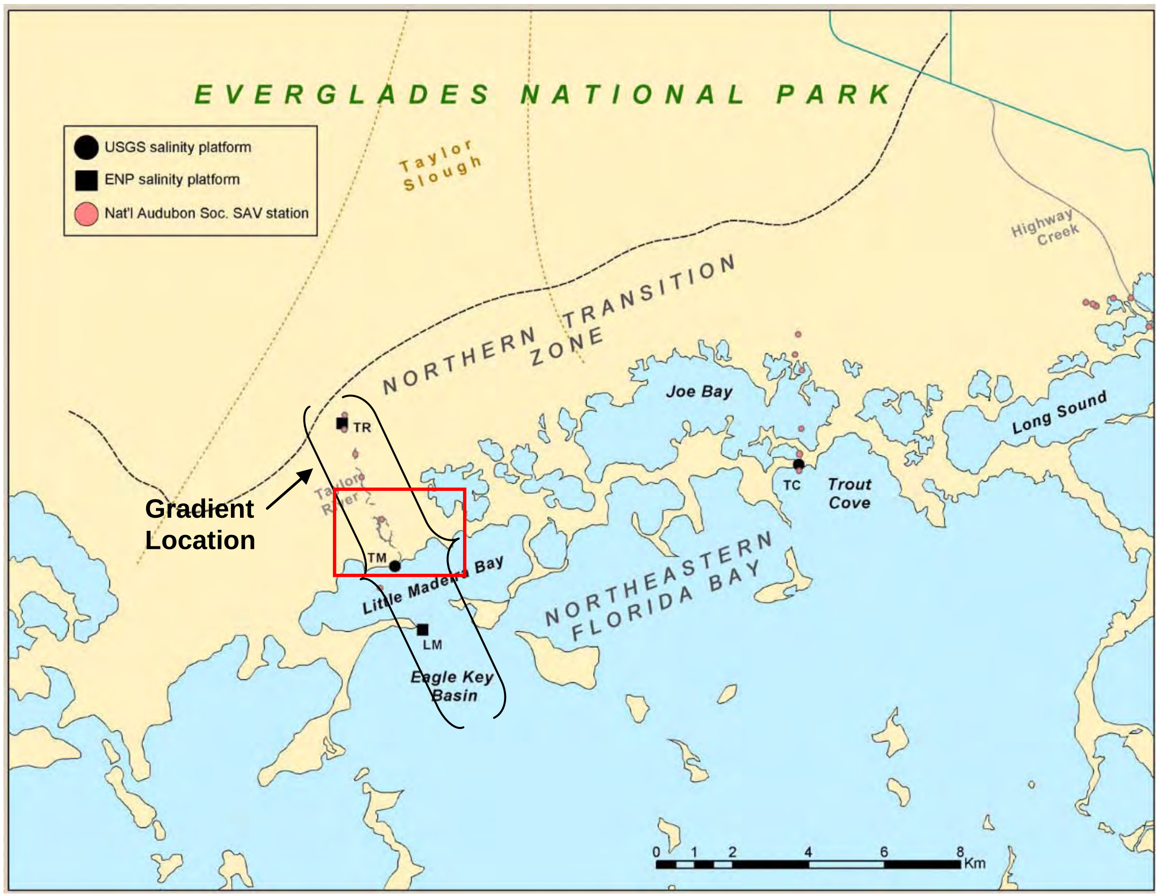


Figure 23. Map of the Everglades–Florida Bay Transition Zone and Northeastern Florida Bay, Showing Gradient Location (the gradient is denoted as { }, with key monitoring stations shown). Red rectangle north of Little Madeira Bay is the area of the image in **Figure 32**.

- The endpoint is a well-mixed location within northeastern Florida Bay (Eagle key Basin) that is similar to most of the rest of eastern Florida Bay. Salinity and biota along this transect respond to freshwater inflows from creeks and sheet flow along the northeast Florida Bay coast.
- Monitoring of flow, salinity, SAV and macroalgae has been ongoing at several locations along this transect. 1) Flows are monitored at the mouth of the Taylor River by USGS. 2) Salinity is continuously monitored at an upstream Taylor River site (TR), at Taylor River mouth (TM) in northern Little Madeira Bay and outside of the mouth of Little Madeira Bay (LM) in northern Eagle Key Basin; salinity is also monitored monthly at the LM site and several other northeastern Florida Bay locations. 3) SAV and macroalgae species have been monitored seasonally in Little Madeira Bay and Eagle Key Basin (Fourqurean et al. 2002) and in the transition zone by the National Audubon Society.
- A multiple linear regression (MLR) model for Taylor River provides reasonable estimates of salinity at the TR site.
- A hydrologic model (FATHOM) for Florida Bay allows robust predictions of salinity along this gradient in Little Madeira Bay and for the adjoining northeast interior Bay region's Eagle Key Basin, accounting for >75 percent monthly salinity variability.

- The transect encompasses a protected sanctuary for the American crocodile, a federally listed endangered species that requires access to fresh water.

The SAV community along this gradient is a critical component of the ecosystem. The presence of SAV species is required for key ecologic functions in the Florida Bay estuarine ecosystem, such as cycling of nutrients, provision of habitat for a range of species, provision of feeding grounds for waterfowl and stabilization of sediment. The presence of an estuarine condition that ranges from low to high salinity is an important feature for maintaining a diverse SAV community—including widgeon grass (*Ruppia maritima*), shoal grass (*Halodule wrightii*) and turtle grass (*Thalassia testudinum*) —that provides plentiful high-quality habitat and is able to support resident biota with needed shelter, food, good substrate and satisfactory water quality through sediment stabilization. The range of salinity is also important for fish and invertebrates that rely on the presence of estuarine conditions for all or part of their life cycle. Model analyses indicate the sensitivity of various fauna to salinity and to habitat quality, which itself is sensitive to salinity.

The technical information that will provide a basis to develop water level and flow recommendations for Florida Bay is presented in this chapter. The information includes historical measurements of flow from structures, water budget descriptions, laboratory mesocosm work on SAV growth and reproduction, field data and observations, literature review and modeling applications.

The modeling synthesizes past and present hydrology to allow a historical reconstruction of inflows and corresponding ecologic effects for Florida Bay and the Everglades–Florida Bay transition zone. This period of record is significant because it includes several periods of low flow resulting from drought conditions, as well as low flow periods resulting from water management activities. Statistical analysis provides evaluation of the transition zone SAV at varying salinity. Seagrass modeling provides evaluation of the Florida Bay seagrass community over the historical period. Statistical modeling of upper-trophic-level species and forage fish assemblage allows for the evaluation of the combined effects of changing salinity and SAV habitat. The following is a brief overview of the modeling approach:

- Hydrologic models were employed to develop a water budget and to predict surface water flows and salinity response leading from the Everglades–Florida Bay transition zone downstream into Florida Bay.
- The ecologic effects of salinity levels were evaluated along a gradient representing three areas of Florida Bay: 1) the Everglades–Florida Bay transition zone, 2) the northeastern coastal embayment area and 3) the open-water area of northeastern Florida Bay. This gradient was used because a relationship between inflow and salinity could be established. The evaluation included reviews of literature, statistical analysis of local monitoring data, analysis of experimental results and the development and application of ecologic models.
- *Ruppia maritima* was selected as an indicator species for the Everglades–Florida Bay transition zone. When salinity conditions are too high to allow Ruppia maritima survival in the transition zone, loss of the existing (predominately fresh water) SAV and macroalgal community is also expected to occur.
- A link between the ecologic health of *Ruppia maritima* in the transition zone and concurrent effects on Florida Bay seagrass communities is presented. When high salinity events cause the loss of *Ruppia maritima* within the Everglades–Florida Bay transition zone, negative ecologic impacts to northeastern Florida Bay can also be inferred, based on ecologic modeling of the SAV and higher-trophic-level species.
- Based on these data, a relationship between freshwater inflow and resource impact was developed for Florida Bay as discussed in Chapter 5.

HYDROLOGIC ANALYSES

Several hydrologic analyses were conducted to support development of flow-salinity relationships for Florida Bay. The present section summarizes 1) application of the mass-balance model FATHOM (Flux-Accounting Tidal Hydrology Ocean Model) to reconstruct a history of estimated salinity within 41 basins located in Florida Bay for period from 1970 through 2002 (see ECT, Inc. 2005) and 2) use of a multivariate linear regression model (MLR) to predict salinity at a station within the Everglades–Florida Bay transition zone (see Marshall et al. 2004).

Mass-Balance Hydrologic Model (FATHOM)

To assist in the development of water level and flow relationship for Florida Bay MFL development, the FATHOM model (ECT, Inc. 2005) was updated to represent 1) freshwater inflows from the upstream wetland and 2) salinity conditions in Florida Bay. The FATHOM model calculates variation in salinity in Florida Bay based on a mass-balance approach. Hydrologic inputs include monthly values of evaporation, sea level, boundary salinity, runoff, rainfall and tides at the boundaries of the model domain, updated to include spatially distributed rainfall and tides and direct measurements of freshwater runoff. Additional refinements were made including compilation of updated bathymetry, inflows and hydrologic data sets, as well as the use of time-varying salinity boundary conditions along the western boundary with the Gulf of Mexico. These updates reflect a significant improvement in detail and reliability of data inputs relative to the previously published description of FATHOM applied to Florida Bay (Cosby et al. 1999).

FATHOM is used to provide quantitative estimates of physical properties (such as basin residence times and salinity) on a monthly time scale under different hydrologic and flow scenarios. A historical reconstruction, spanning the period from 1970 to 2002, was developed to provide historical salinity estimates and annual water budgets for the 41 basins in Florida Bay. A water budget was constructed because this period comprises a wide range of climatic and inflow variations. Data that define the historical reconstruction period include estimated monthly rainfall, evaporation and freshwater inflow to the Bay from the mangrove transition zone. The “base case” salinity predictions were based on calibration analyses from 1991 to 2002, a period with a comprehensive set of observed hydrologic data (ECT, Inc. 2005).

Water Budget

The Everglades–Florida Bay transition zone is an area of extensive mangrove wetlands consisting of shallow swamplands, creeks, ponds and bays along the mainland shore of northern Florida Bay. The major source of fresh water into Florida Bay traversing this ecotone is flow from the Taylor River and a series of approximately 20 creeks carrying surface water from the Taylor Slough/C-111 drainage area into the Bay. The much larger Shark Slough basin, which under most conditions is hydrologically separate from the Taylor Slough/C-111 basin, drains into the Gulf of Mexico and is not considered in this study. Direct measurements of freshwater inflow into Florida Bay have been made since 1996 by the U.S. Geological Survey from five gauged creeks discharging into the Long Sound, Joe Bay, Little Madeira Bay and Terrapin Bay coastal embayments. Evidence from natural- tracers suggests that submarine groundwater discharge into Florida Bay contributes only slightly to the net freshwater supply (Corbett et al. 1999); therefore, this component is not included in the water budget. Ungauged flow has been estimated by the USGS in four additional creeks as constituting roughly an additional 23 percent of the gauged inflow (Hittle et al. 2001). Except for these empirical relationships, there appears to be no other information on the magnitude of the ungauged discharge of fresh water from the Everglades directly into Florida Bay. In any case, ungauged surface flow and ungauged groundwater are expected to be greater in periods of high inflow rather than during the low inflow periods that are the focus of the present evaluation.

Fresh water first flows through extensive mangrove wetlands consisting of shallow swamplands, creeks, ponds and bays before reaching open portions of northeastern and coastal central Florida Bay. Florida Bay's watershed within the southern Everglades can be subdivided into three regions: 1) Long Pine basin, 2) Taylor Slough and 3) the C-111 basin (**Figure 24**). Discharge from Long Pine basin is the result of rainfall in excess of evaporation within the basin—there is no large surface inflow to this basin. Flow through McCormick Creek, the only gauged surface outflow from the Long Pine basin, occurs intermittently (ECT, Inc. 2005). Freshwater flow from Taylor Slough is a function of rainfall, evaporation and management of the L-31 Canal and associated structures at the head of the slough. Flow from the Taylor Slough subregion discharges into the Bay via many small creeks, including Taylor River (which is the largest of these creeks.) Most of the water that flows from the C-111 Canal basin into the Bay first travels from the canal into mangrove wetlands, then through many small creeks into Joe Bay or Long Sound and then into northeastern Florida Bay. During periods of relatively high flow, the S-197 structure located at the terminus of the C-111 Canal is opened and water discharges into Manatee Bay, which is part of the Biscayne Bay system.

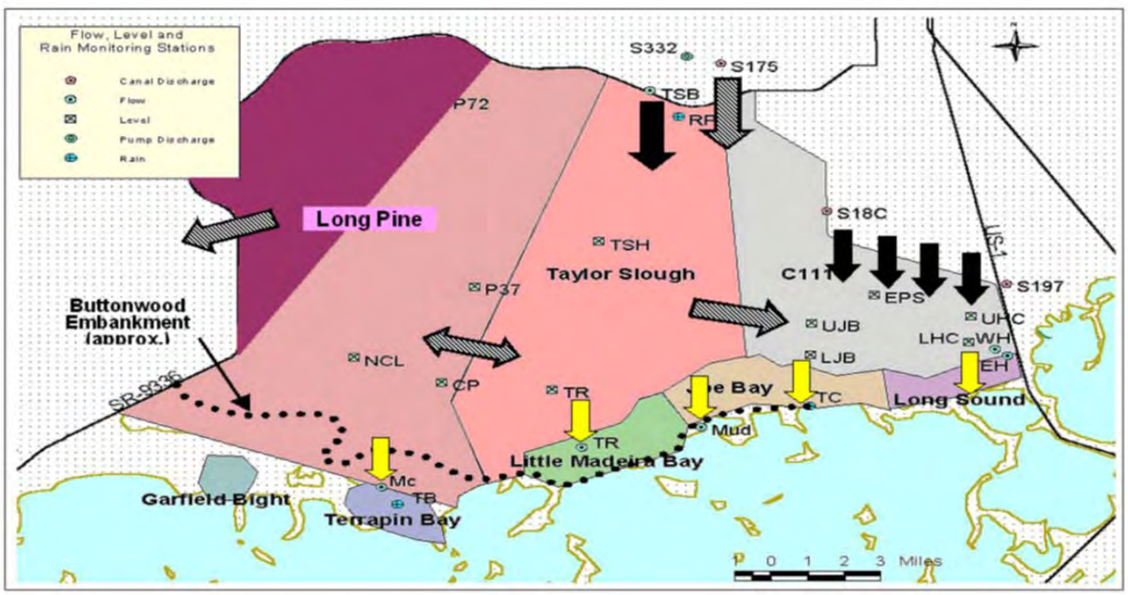


Figure 24. Wetland Basins Used in the Hydrologic Analyses. Arrows show surface inflows to the wetland basins included in the water balance calculations [black], location of USGS measured creek flows (yellow) and calculated surface fluxes (hatched).

Long-term records (since 1970 for the canal control structures) of freshwater inflow to the southern Everglades include the records of flow at Taylor Slough bridge (TSB), which lies within Taylor Slough, and at canal structures S-175, S-18C and S-197 (**Figure 24**). The TSB and S-175 flows are the principal sources of surface water inflow into the Taylor Slough wetland basin. The S-18C flow minus the S-197 flow provides the basis to estimate overland discharge from the C-111 Canal into the downstream C-111 wetland basin and ultimately into the northeast corner of Florida Bay. The input to the FATHOM historical reconstruction includes some additional flow added to the measured flow at structures to account for excess rainfall over the wetland and for ungauged flow as detailed by ECT, Inc. (2005). Total average annual inflows to northeast Florida Bay from these sources show an increasing trend for the 31-year period 1970–2000 (**Figure 25**).

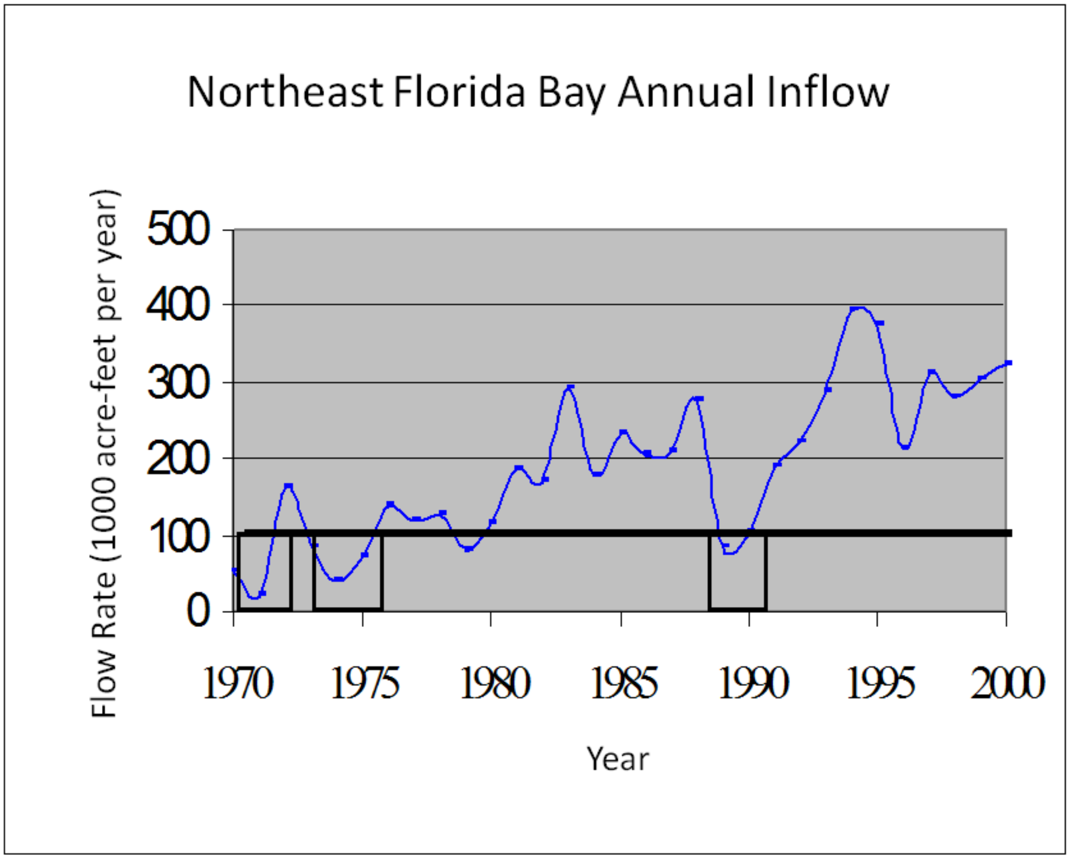


Figure 25. Annual Overland Inflow to Northeastern Florida Bay, 1970–2000. This information is an input to the FATHOM model and is based on measured structure flows (Taylor Slough Bridge + S18C – S197); additional flow was added to the measured structure flow in the FATHOM model to account for excess rainfall over the wetland and ungauged flow as detailed by ECT, Inc (2005); boxed areas correspond to periods in which annual inflows (indicated by the symbols) fall below 105,000 acre feet/year for more than two consecutive years.

Sensitivity to Rainfall Variations

Patterns and distributions of rainfall were examined for the Everglades watershed and Florida Bay to determine the amount of rain typical of dry, normal and wet years (**Figure 26**). Rainfall data for the 31-year period 1970–2000 were ranked separately for the Everglades and Florida Bay. Rainfall analyses representing the Everglades (Shark River Slough and the Water Conservation Areas) were used from the Florida Climate Division 5 rainfall records (ECT, Inc. 2005); Division 5 records include data from numerous gauges within south Florida as compiled by the National Climatic Data Center of the National Oceanographic and Atmospheric Administration (NOAA). Florida Bay rainfall analyses were based on the spatially variable rainfall data from three stations bordering Florida Bay (Flamingo, Tavernier and Royal Palm) as described by ECT, Inc. (2005). In order to aid in the water budget interpretation, dry, normal and wet years were selected as years ranking near the 10 percent (dry), 50 percent (normal) and 90 percent (wet) thresholds of the annual rainfall distribution over the 31-year period.

Water Year	Fl. Bay Rainfall	Water Year	Div. 5 Rainfall
1989	31.7	1976	41.4
1971	34.7	1971	42.72
1986	35.7	1985	44.02
1974	36.2	2000	44.45
1985	40.9	1990	44.71
1990	41.4	1981	44.81
2000	43.4	1977	45.55
1980	43.5	1972	46.53
1984	43.6	1989	46.55
1977	45.4	1988	46.91
1970	45.9	1980	47.03
1994	46.3	1996	47.38
1979	49.2	1974	47.85
1992	49.5	1975	48.62
1987	49.6	1997	48.97
1996	50.4	1987	49.78
1975	51.4	1986	50.5
1991	52.4	1984	50.91
1976	54.0	1973	51.09
1993	54.9	1992	52.31
1998	55.0	1994	53.6
1978	55.6	1979	53.69
1972	55.7	1993	55.15
1997	57.5	1978	55.67
1973	60.8	1970	57.46
1982	61.3	1991	57.53
1988	63.6	1998	57.56
1981	63.8	1983	59.8
1999	67.3	1982	60.41
1983	71.7	1999	63.22
1995	72.4	1995	78.2

Dry

Normal

Wet

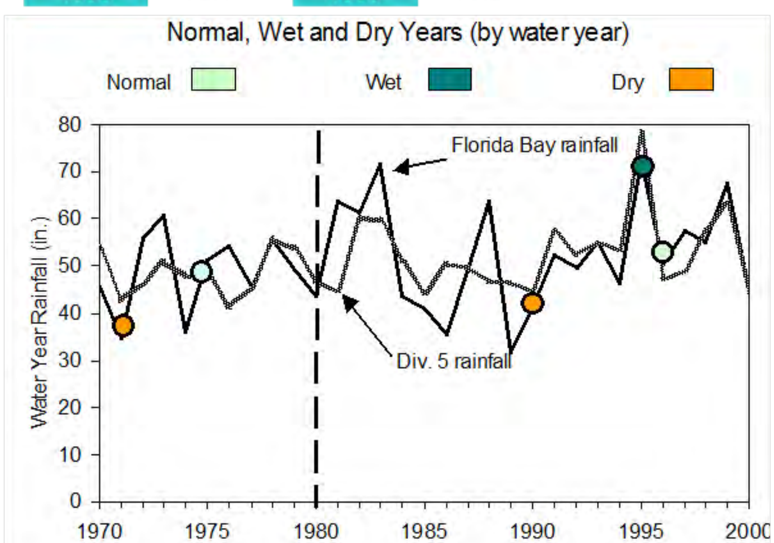
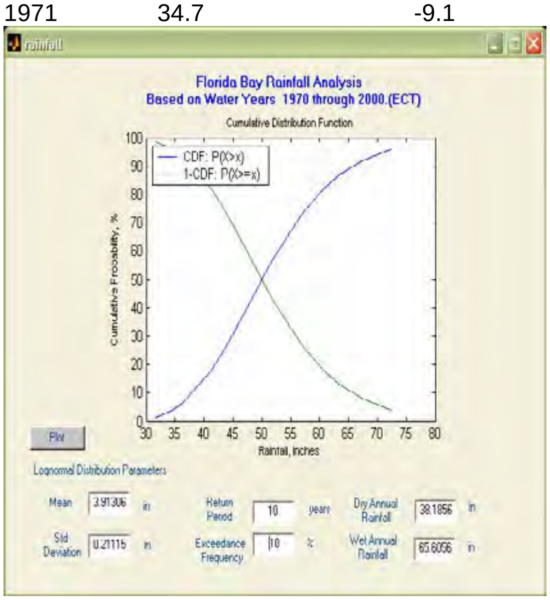


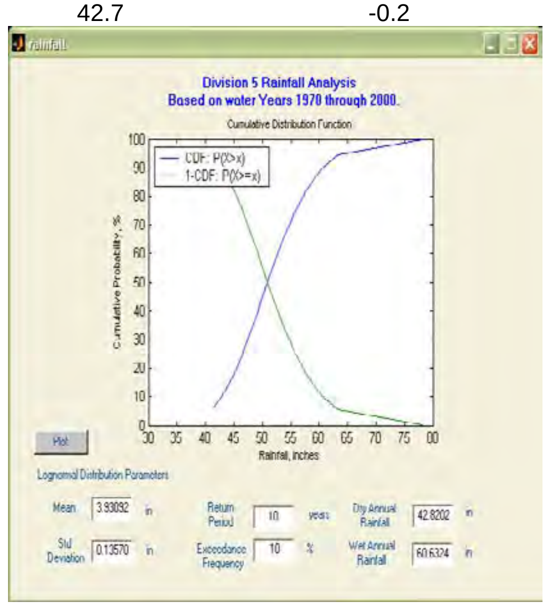
Figure 26. Ranking of Normal, Wet and Dry Years . This analysis is based on Florida Bay rainfall [used as FATHOM input] and Everglades rainfall [Div. 5] for 1970–2000; the water year is defined as November 1–October 31; rainfall patterns spatially differ, resulting in marked differences in rainfall amounts between Florida Bay and the southern Everglades [Div. 5] during some years; these years were excluded from the selection of representative wet, normal and dry years (ECT, Inc. 2005).

The 31-year record shows two representative drought years (November 1–October 31) near the 10 percent dry threshold level: 1971 and 1990 (**Table 9**). The two years were considered representative of a 1-in-10 year drought condition (defined as the 10 percent threshold having a return period of 10 years, thus occurring once every ten years on average). The year preceding the 1990 drought (1989) had the lowest rainfall measured over Florida Bay during the 31-year period of record, while the Everglades (Division 5) annual rainfall was more moderate (Error! Reference source not found.). Thus, Florida Bay felt the effects of near 1-in-10 year drought conditions for two consecutive years. The pre-1980 period shown was representative of conditions that were drier than normal (**Figure 26**) and does not contain a representative wet year (ECT, Inc. 2005).

Table 9. Representative Drought Years. The 10 percent threshold and deviation of the historical representative years were compiled using 1970–2000 data. The 10 percent threshold for the Everglades (Division 5) = 42.82 inches and for Florida Bay = 38.18 inches; these results are comparable to the 10 percent threshold calculated using data from the Flamingo (36.4”, 40-year record) and Tavernier (30.8”, 63-year record) rainfall stations.

	Florida Bay		**Everglades**	
	Water year rainfall (inches)	Difference (in percentage points) from the 10 percent dry threshold	Water year rainfall (inches)	Difference (in percentage points) from the 10 percent dry threshold
1990	41.4	8.4	44.7	4.4
1971	34.7	-9.1	42.7	-0.2





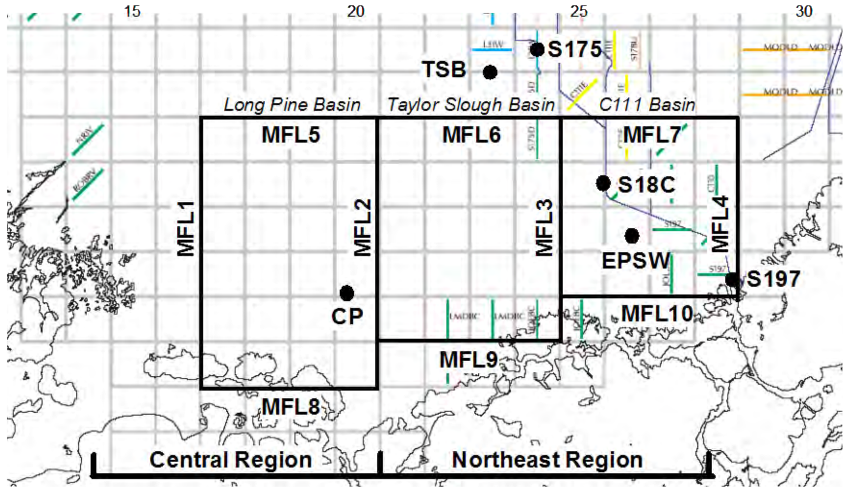
Sensitivity to Variations in Inflow from Canals

A notable factor affecting Florida Bay during the study period was that surface water discharges through Taylor Slough Bridge (TSB) and C-111 Canal were low in the period 1970–1981 relative to flows after 1981. As a result of changes in water management activities (**Table 2** and **Figure 13**) flows into the Everglades–Florida Bay transition zone increased by about a factor of four, relative to rainfall, after 1981. This is perhaps the most significant change that occurred in Florida

Bay's freshwater budget during the period 1970 through 2000. To take this factor into account, normal and dry years were defined in both the pre-1980 and post-1980 periods, for comparison.

The period from 1973 to 1975, a period of low water delivery to the system, is highly variable, containing dry to wet years depending on year and location over Florida Bay or over the watershed. The water year 1975 was normal in terms of precipitation but had total annual inflow -- comparable to the 1989–1990 drought period (**Figure 27**). This illustrates effects of 1960–1980 regional water management activities that decreased flow to the mangrove transition zone.

a



b.

Source of Freshwater Inputs	Pre-1980						Post-1980								
	Dry Year - 1971			Normal Year - 1975			Dry Year - 1990			Normal Year - 1996			Wet Year - 1995		
	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total
Direct Freshwater Inputs															
1. Rainfall	452	78	530	472	306	778	395	245	640	576	218	794	688	447	1135
2. Evaporation	-428	-445	-873	-420	-477	-896	-503	-536	-1039	-377	-380	-757	-400	-463	-863
Net from Atmosphere	23	-367	-344	52	-171	-119	-108	-291	-399	199	-162	37	288	-15	273
Inflows from Mangrove Transition Zone															
Budget for Taylor Slough Basin:															
3. MFL6 - Taylor Slough bridge and S-175	1	0	1	7	0	7	18	0	18	56	31	87	124	70	195
4. MFL2 - flow from Long Pine basin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5. MFL9 - inflow to Madeira, Little Madeira	2	0	2	7	1	8	9	2	11	19	7	26	25	22	47
Budget for C-111 Basin:															
6. MFL7 - S18c flow	2	1	3	23	0	23	57	10	67	115	32	147	197	154	351
7. MFL3 - flow from Taylor Slough basin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
8. MFL4 - outflow via S197 to Manatee Bay	0	0	0	0	0	0	0	0	0	27	0	27	93	20	114
9. MFL10 - inflow to Joe Bay and Long Sound	14	1	15	48	7	54	66	11	77	133	51	184	174	155	329
Budget for Long Pine Basin:															
10. MFL5 - flow across Park road	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
11. MFL1 - flow across Park road	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12. MFL2 - flow to Taylor Slough	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
13. MFL8 - inflow to McCormick Creek and central region	2	0	2	7	1	8	10	2	12	21	8	29	27	24	51
14. Freshwater Inputs from All Sources (1+5+9+13)	470	79	549	534	315	848	480	260	740	749	284	1033	915	648	1563
15. Freshwater Inputs from Mangrove Transition Zone (5+9+13)	18	1	19	62	9	71	85	15	100	173	66	239	226	201	428

nd - no data available

Figure 27. Simplified Water Budget for Northeast and Central Florida Bay: (a) Wetland Basins Used to Estimate Freshwater Inflow through the Everglades–Florida Bay Transition Zone (locations of the flow transects are superimposed on the grid of the SFWMM model; also shown are locations for flow [TSB, S175, S18C and S197] and wetland

water levels [CP and EPSW]); (b) Flows Reported for Water Year November 1 1994 – October 31 1995 Pre- and Post-1980 (in 1000 ac-ft per year).

Effects of Inflow Changes upon Salinity

The average annual water budget for Florida Bay for the period 1970–2000 was compiled using the FATHOM base case (ECT, Inc. 2005). Rainfall and evaporation dominate the freshwater budget. On an annual basis, inflow is typically only about 20 percent of rainfall in the central and northeastern regions of the Bay, but inflow's contribution is necessary to maintain a net positive inflow in late summer and fall (**Figure 28**).

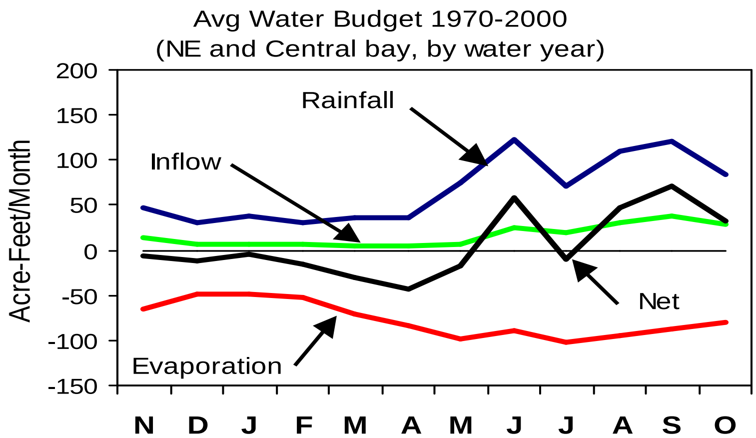


Figure 28. Average Water Budget, 1970–2000 . Evaporation and direct rainfall are the largest fluxes of fresh water into northeast and central Florida Bay; "net" refers to the difference between these terms; direct inflow is not overall a large component of the annual water budget but accounts for more than one-third of the net freshwater supply in late summer through the fall (ECT, Inc 2005).

A minimum flow specification will be ecologically relevant only to those parts of the Bay that are influenced by inflow. Using results from the FATHOM hydrologic analyses, a linear statistical model was developed (ECT, Inc. 2005) to assess whether annual maximum salinity values within Florida Bay were sensitive to inflows and direct precipitation. Maximum annual salinity was indicated as being sensitive to inflow, rainfall or water level if the corresponding coefficient in the linear model tested significantly different from zero at the p=0.05 level. Bay basins in which annual maximum salinity is significantly correlated to year-to-year changes in inflow are clustered in the northeast and eastern interior (**Figure 29**).

Models for Bay basins indicated that inflow changes did not explain the variation in maximum annual salinity in the west and western portion of the south region, presumably because maximum annual salinity values in those areas are a function of local rainfall and evaporation and salinity variation on the open western boundary of the Bay. Western boundary conditions are primarily driven by changes in freshwater discharges from Shark Slough (which are not part of the flow analyses) and by oceanographic processes in the Gulf of Mexico.

In the central region (light blue area in **Figure 29**) the apparent lack of influence of inflow on maximum salinity may simply reflect the fact that very little or no inflow reaches the central region during dry years. In contrast, annual maximum salinity at select locations in the central Bay are significantly correlated with wetland water levels (ECT, Inc. 2005). Given the small amounts of direct inflow to this region, however, additional analyses would be needed in order to quantify a relationship between water level and inflow in order for this finding to be useful for minimum flow determination. It is possible that much of the inflow that eventually enters the central Bay first flows into the northeast Bay and the complex mixing and circulation dynamics within the Bay determine the extent to which this freshwater influences the central Bay. A quantitative estimate of this influence requires a hydrodynamic model, which is currently being developed as part of CERP's Florida Bay and Florida Keys Feasibility Study.

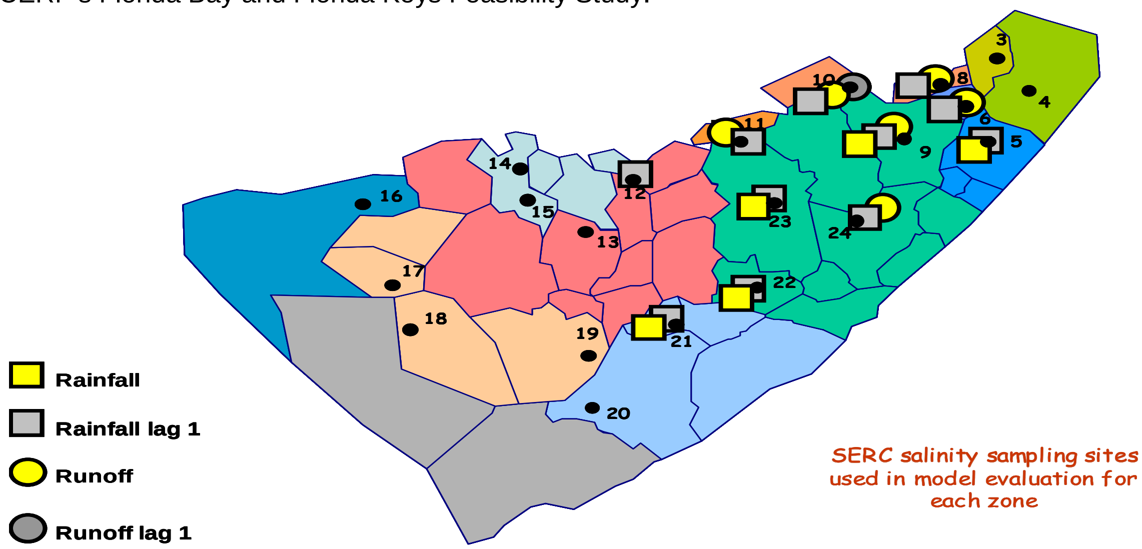


Figure 29. Regions of Inflow Sensitivity. The lag 1 analysis incorporates prior years' annual rainfall or runoff; shown are basins in Florida Bay where annual maximum salinity [calendar year basis] is significantly correlated to annual inflow in addition to annual rainfall; such areas are clustered in northeast Florida Bay; the regions are colored consistent with FATHOM analyses (ECT, Inc. 2005).

The FATHOM model was used to develop a 33-year monthly mean salinity time series for each of the 41 individual basins within Florida Bay (ECT, Inc. 2005). This base case represents the reconstruction of the water budget as close to historical conditions as possible. As illustrated by the calibration period (1991–2002), model fidelity and predictions varied somewhat by basin (**Figure 30**). Overall, the FATHOM model is capable of explaining about 81 percent of the monthly salinity variability throughout the 41 basins modeled within Florida Bay (ECT, Inc. 2005).

Performance of FATHOM varied from area to area. In general terms, the best performance was achieved in the northeast and eastern basins (shown as orange and blue-green basins in **Figure 30**. The lowest efficiency in these regions was in Joe Bay. Predictions in all regions do not reflect the monthly range of possible upper and lower daily extremes. It is important to recognize that the monthly mean predictions by FATHOM are compared against grab sample measurements taken during the month of comparison.

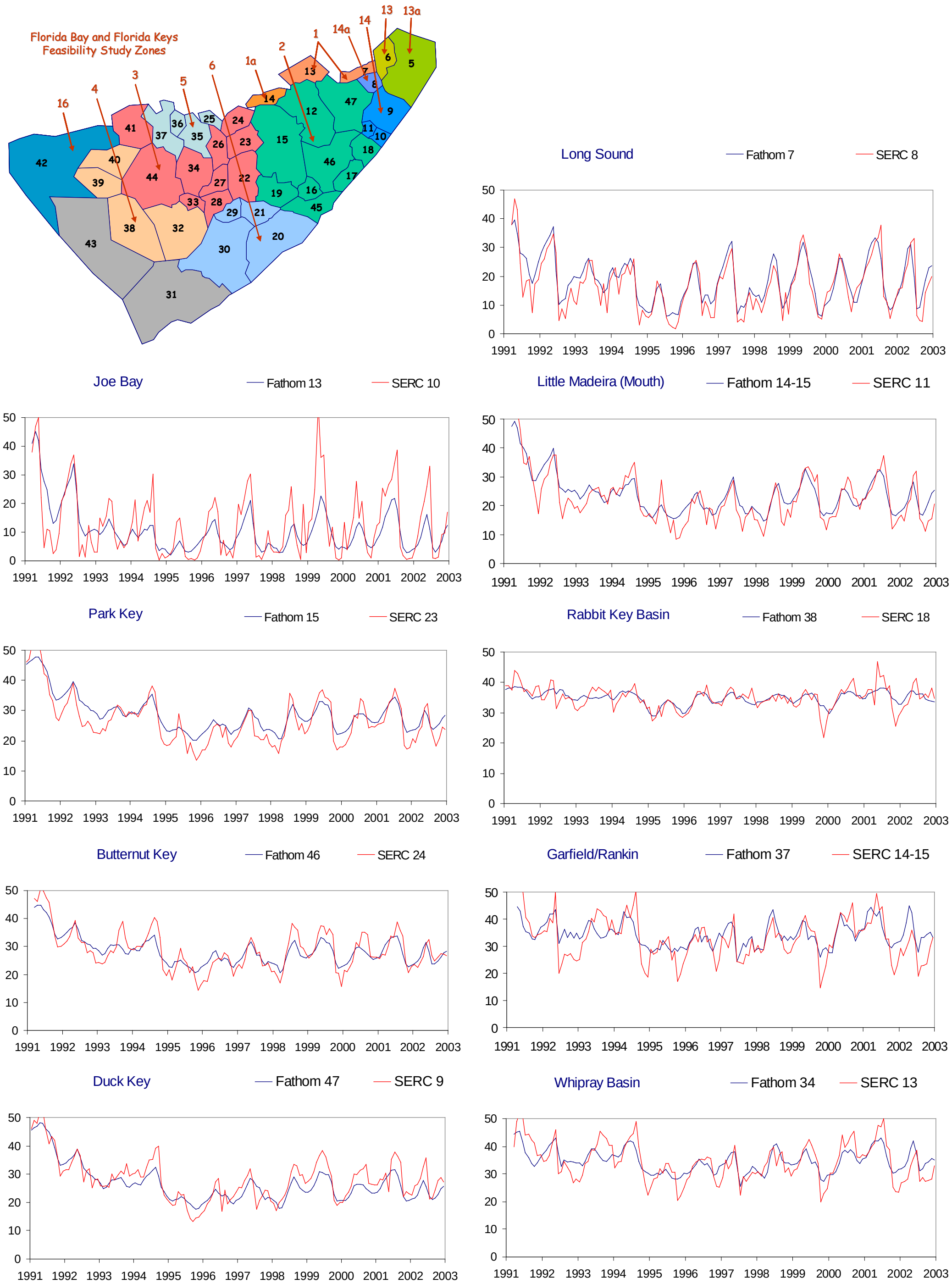


Figure 30. Time Series for Selected Florida Bay Basins, Showing FATHOM Predictions and Observed Values (SERC sampling stations). The inset at the upper left shows the location of the FATHOM basins; in the present report, further analyses are shown for Little Madeira Bay (FATHOM basin 14) and for Park Key (FATHOM basin 15, referred to also as Eagle Key Basin) (ECT, Inc. 2005).

Everglades–Florida Bay Transition Zone Salinity Model

Analysis to determine water level and flow criteria for Florida Bay requires estimating salinity in the Everglades–Florida Bay transition zone (**Figure 23**). The FATHOM model estimates do not extend into that zone, and so a statistical modeling approach was used. The Taylor River station (TR) is located in this ecotone along the representative gradient and is part of the ENP Marine Monitoring Network; thus TR is used in the present analysis as an indicator site for the transition zone. During wet periods, fresh water flows past the TR station through Little Madeira Bay and into northeast Florida Bay. During dry periods, salt water from Florida Bay can migrate into Taylor Slough, resulting in high-salinity levels at the TR station.

Salinity has been recorded at TR by Hydrolab® sondes at ten-minute intervals since July 14, 1988, with numerous periods of days to weeks of missing data, particularly at the beginning of the data record. As part of the modeling work, a salinity time series for the TR station for the period 1970 through 2002 was constructed (Marshall 2004a, 2005). The historical reconstruction is based on continuous salinity-monitoring data, which was available beginning in October 1988. In addition, the existing multivariate linear regression (MLR) salinity model was used to predict salinity for the period from 1970 to 1988 (Marshall et al. 2004). Data from these two sources were combined to create the historical reconstruction. This procedure is described in more detail in Chapter 5. The daily value salinity model is as follows:

TR salinity = 83.17 - 15.09*CP[lag4] + 0.835*Kwwatlev - 7.83(P33-P35)[lag1] - 4.34(P33-P35)[lag4]

where:

CP = stage (feet NGVD) at Craighead Pond

Kwwatlev = Key West water level (MSL)

P33 = stage (feet NGVD) at P33

P35 = stage (feet NGVD) at P35

Lag1 = one-day lag

Lag4 = four-day lag.

Ideally, the historical reconstruction should be applied on a monthly time scale (consistent with FATHOM). Thus the daily simulated values produced by the Taylor River MLR model were averaged to monthly values. Details on model development can be found in Marshall et al. (2004a, ECT, Inc 2005). Efficiency (a measure of the percentage of variance that is explained by the model variability) of the monthly Taylor River MLR salinity model is 84 percent (**Table 10**). The Taylor River model predictions compare reasonably well with observed values for the period 1988–2000, when observations exist (**Figure 31**).

Table 10. Summary of Uncertainty Statistics for the Monthly Taylor River MLR Salinity Model.

Station	mean sq error (psu)	root mean sq error (psu)	adj R-sq	mean error, (psu)	mean abs error, (psu)	max abs error, (psu)	Nash-Sutcliffe Efficiency
Taylor River	12.71	3.56	0.84	-0.49	2.63	9.34	0.84

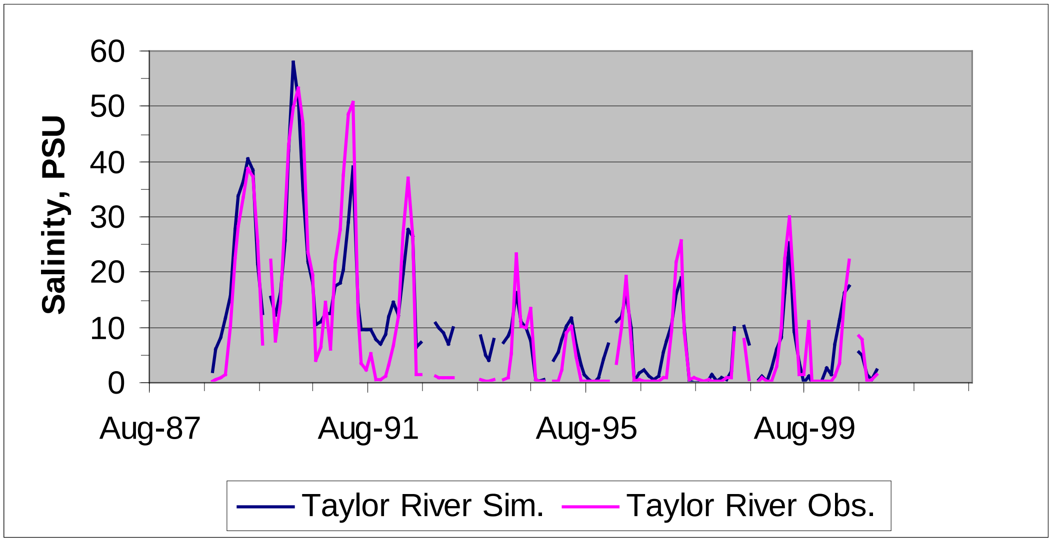


Figure 31. Predicted and Observed Average Monthly Salinity at the Taylor River (TR) Site. The highest error is associated with relatively short periods at onset of the wet season.

Examination of the daily and monthly plots and the daily uncertainty statistics indicates that the daily simulated values have an error of about 4.5 psu (Marshall 2004a). Some daily values may be as much as 10–15 psu in error during the month of May and, to a lesser extent, April, June, August and September because of interannual variability in the onset of the wet season. As with the daily values, monthly average salinity values are typically within 4 psu of observed values. Because of the potential for large residuals, particularly at the daily level, the following model limitations are apparent:

- The highest variability is associated with the relatively short period in which the dry season is ending and the wet season is beginning; the exact date and extension of this transition are not predictable (**Figure 31**).
- Measured flow in Taylor Slough can cease for relatively long periods, and so salinity simulations have the potential for high variability among extended low flow periods. Unfortunately, the reconstruction period contains two periods of extended low flow (namely, 1970–1974 and 1985–1990), and the 1970–1974 reconstruction should be viewed with this in mind. Observed values during the 1985–1990 dry period reached 60 psu, and maximum values during the 1970–1974 period probably also reached into that range.

ESTIMATING ECOLOGICAL EFFECTS OF WATER LEVELS AND FLOWS FOR MFL DEVELOPMENT

The ecologic characteristics of estuaries are strongly related to the influx of fresh water and associated materials from their watersheds (Day et al. 1989). Foremost among the influences of this watershed linkage is the effect of freshwater flow on the range and variability of salinity within estuaries. Salinity is a primary determinant of the species composition of communities and strongly influences functions of these communities (Sklar and Browder 1998). Altering the freshwater flow can also change the supply of nutrients to the estuary, thereby affecting estuarine productivity and habitat quality and availability.

Organisms living in the estuary have characteristic salinity tolerances and optimal salinity. Thus Florida Bay's salinity regime will determine how well these organisms can function, whether motile organisms will move out of the estuary to seek habitat offering more suitable conditions and whether certain other organisms will perish. Individual organism and population functions, in turn, determine the health of the entire ecosystem. If individual species are impaired by salinity stress, other components of the system that depend on them are endangered as well, resulting in a wider degree of systemic impairment of the ecosystem. For instance, a decline in the abundance or quality of seagrass habitat will have a detrimental impact on fauna that utilize this habitat. A decline in populations of small forage fish or invertebrates will have a detrimental impact on publicly recognizable sport fish populations. In this manner, the detrimental effects of salinity can cascade through the ecosystem.

All estuarine organisms are physiologically affected to some degree by the salinity level and by the rate of salinity change within an estuary. At extreme levels or with very rapid changes, salinity stress can be directly lethal to organisms, causing death in a relatively short time. Less extreme salinity stress may not be lethal but may nevertheless be just as important to the ecosystem; sublethal effects can include decreased growth and reproductive success, yielding a slow decrease in populations and changes in the structure and function of the food web.

Responses by animal species to changing freshwater inflow are not simply a matter of physiological tolerance. For instance, an important function of freshwater input is the seasonal appearance of a low-salinity signal that guides migrating organisms toward the nursery grounds in the wetlands (Shaw et al. 1985). Shrimp, certain fish species (such as menhaden and mullet) and other nekton have been shown to follow the salinity gradient toward a freshwater source, where they seek shelter to spawn or to complete their life stages and to consume special diet items while growing (Day et al. 1989). Without the appearance of the low-salinity signal at some distance from the freshwater source, offshore resident species may be disconnected from their inshore spawning and nursery grounds, resulting in reduced fisheries productivity or even in the demise of the species in that area.

The spatial expanse of estuarine conditions is also important in considering the potential ecologic effects of water levels and flows. The estuarine zone is a region of intermediate salinity created by the mixing of fresh and salt water and, absent freshwater inputs, the estuary would eventually change into a marine and hypersaline system. As the amount of freshwater input declines, the areas characterized by estuarine salinity generally diminish, resulting in less estuarine habitat and reduced area for feeding, fishing and spawning, processes that depend on the estuarine environment. Browder and Moore (1981) and Sklar and Browder (1998) emphasized the importance of the overlap of estuarine conditions and appropriate habitat (such as SAV or mangrove prop roots) for animal species. Decreases in the area of overlap, either by changes in habitat quantity or quality or by the occurrence of salinity conditions inhospitable to fauna, will decrease these faunal populations and ecosystem productivity. Furthermore, many animal and plant processes are not linear with respect to space; certain minimum areas and spatial configurations (such as corridors) are required in order for some processes to occur (Micheli and Peterson 1999). Examples of spatial requirements are range area for mobile organisms, minimum predator-prey encounter areas, minimum refugia area for protective habitat and minimum sustainable seagrass patch size. Freshwater flows and salinity affect such biotic behavior and interactions both directly and indirectly by setting the spatial scale at which these processes occur. Thus, in addition to their direct salinity effects on biological organisms, changes in freshwater flow result both in systemwide changes in the physical size of the entire estuarine ecosystem and in local changes in spatial dimensions required for many ecologic processes.

The present section describes five types of analyses that were used to evaluate the ecologic effects of salinity conditions that will be used provide a basis for Florida Bay MFL criteria recommendations.

- General literature and data on important Florida Bay species were examined in order to determine the ecologic significance of these species and the environmental (salinity) conditions required for their survival.
- Field data from Florida Bay submersed aquatic vegetation (SAV) beds were analyzed and summarized to show, when possible, the statistical relationships among environmental conditions, distribution, cover and density.
- Analysis was performed on the results from mesocosm experiments on environmental tolerances and physiological responses of Florida Bay's SAV species.
- Modeling analysis of the field and mesocosm data was performed using a seagrass simulation model developed and calibrated specifically for Florida Bay. The model shows the predicted behavior of the seagrass community in response to different flow and salinity regimes.
- Statistical models were developed specifically for Florida Bay fish and invertebrate species to show the relationships among faunal densities, environmental parameters and seagrass composition and density.

The results of these five lines of analysis show that when the Everglades–Florida Bay transition zone and northeastern Florida Bay are exposed to marine and hypersaline conditions, biota are negatively affected and habitat is lost. A minimum freshwater inflow standard is critical for Florida Bay in order to ensure survival of critical ecosystem functions and species. The evaluation described in the following pages identifies 1) an individual species (*Ruppia maritima*) that is an overall indicator of the freshwater SAV community in the transition zone and 2) when monthly average salinity in the transition zone increase above 30 psu, the freshwater SAV community in this zone is lost and marine salinity may persist downstream for several months, resulting in adverse changes to seagrass communities in northeastern Florida Bay.

Everglades–Florida Bay Transition Zone and Its Submersed Aquatic Vegetation

The Everglades–Florida Bay transition zone is an ecotone containing numerous creeks, ponds, lakes and wetlands that include mangrove swamps and saline marshes (**Figure 23** and **Figure 32**). Hydrologic conditions in this zone are influenced by sheet flow and seepage of fresh water from the Everglades and by the intrusion of water from Florida Bay driven by wind and to a lesser degree by astronomical tides. Along the northeast and north-central Florida Bay coast, water exchange between the Bay and the transition zone occurs in creeks that cut through a low-lying coastal ridge.

This transition zone is a major component of the greater Everglades ecosystem, with ecologic links to both Florida Bay and the freshwater Everglades, and it is a focus of the Comprehensive

Everglades Restoration Plan (Davis et al. 2005). In particular, the mangrove ecotone is an area that historically supported large populations of wading birds and waterfowl by providing a food base in the ponds and marshes and a place for rookeries in the nearby mangrove forests. These bird populations greatly decreased in the last century, probably in association with the hydrologic alteration of the Everglades and increased salinity in the transition zone (McIvor et al. 1994, Davis et al. 2005), but this zone still supports critical populations, including wood storks (an endangered species) and roseate spoonbills (a Florida species of special concern). This zone is also of special importance because it is the home of most remaining American crocodiles (an endangered species) in the United States (Mazzotti 1999).

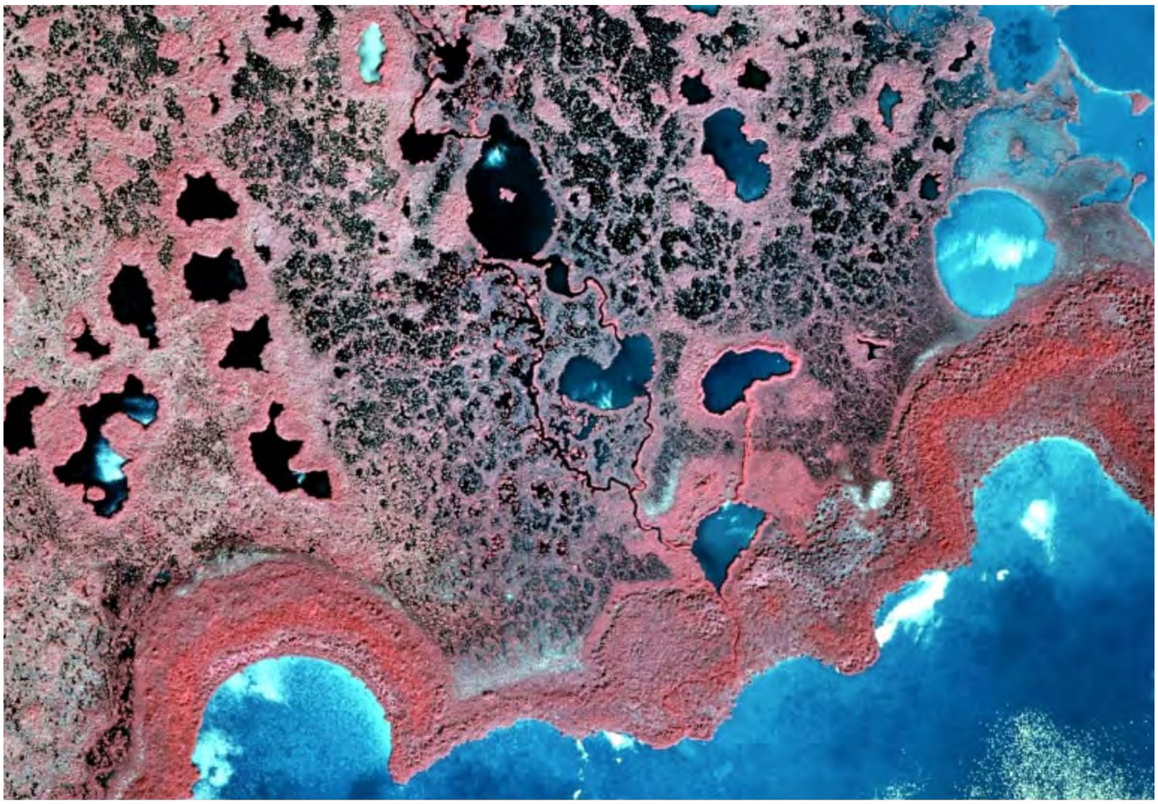


Figure 32. Satellite Image of the Salinity Transition Zone near Taylor River. The area shown by this image is north of Little Madeira Bay (see **Figure 23**). Color patterns show the heterogeneity of the landscape, including many ponds; dark red-pink areas fringing the shorelines of the Bay and ponds are canopies of red mangroves; the distance from the southern [lower] shoreline to the northern [upper] edge is about 2 km.

Geomorphology and the salinity gradient within the transition zone from the Everglades to the Bay are primary factors structuring ecologic zones within the transition zone, as described by Ross et al. (2000, 2002). Wetlands found at the boundary of the Bay and bordering numerous mangrove creeks and ponds within about five kilometers of the Bay are dominated by *Rhizophora mangle* (red mangrove) trees (**Figure 32**). Adjacent interior saline wetlands are also dominated by red mangroves, but these mangroves are dwarfed and in the form of shrubs because of nutrient limitation (Koch and Snedaker 1997). Toward the interior of the transition zone, marshes contain a mixture of mangrove shrubs and graminoid vegetation (grasses and grasslike plants, such as sedges: mostly *Eleocharis* spp. and *Cladium jamaicense*). Much of this zone has low productivity and sparse vegetation and appears as an area of high reflectance in satellite images (a “white zone,” Ross et al. 2000). The area of this white zone has increased during the past fifty years, with the interior boundary extending inland by up to four kilometers—a shift hypothesized to be the result of increased saltwater intrusion associated with reduction of freshwater input from upstream and occasioned by changes in water management. *Cladium jamaicense* (sawgrass) dominates the freshwater boundary of the transition zone.

Transition zone wetlands are an important foraging area for wading birds. Lorenz (1999) has described productivity patterns of fish related to salinity and water levels that constitute the forage base for such birds as the roseate spoonbill, finding that the density and biomass of this forage assemblage, which is dominated by members of Cyprinodontidae (killifishes), Poecillidae (livebearers), Gobiidae (gobies) and Atherinidae (silversides) tend to decrease with increasing salinity and increase with longer, more-stable hydroperiods. Experiments by Rowe and Dunson (1995) suggest that these results could stem from an interaction of fish concentration (prey density) and salinity factors: in their work, growth and survival of *Cyprinodon variegatus* (sheepshead minnow), a common species in the mangrove transition area) were reduced at higher salinity (32 psu) when combined with high fish density. Foraging success of wading birds is highly dependent upon the decreasing water levels in the early dry season, which concentrate prey for the birds (Frederick and Spalding 1994, Davis et al. 2005).

Submersed aquatic vegetation in transition zone waters is important as a base of the food web and as habitat. In particular, *Ruppia maritima* (widgeon grass), the dominant vascular plant of this SAV community, is known to be an important food source for wintering waterfowl, including coot, scaup, widgeon and pintail (Kushlan et al. 1982). The abundance of these waterfowl populations in transition zone ponds has greatly decreased in the past fifty years (Davis et al. 2005), a drop hypothesized to be the result of declines in SAV productivity and cover because of increased salinity and prolonged periods of high-salinity conditions within naturally oligohaline and mesohaline ponds (Morrison and Bean 1997, Montague et al. 1998, Davis et al. 2005). Isotopic studies of the transition zone food web (in Whitewater Bay) suggested that *Ruppia* was a major food source for forage fish and invertebrates that were the food base for gray snapper (Harrigan et al. 1989).

Field observations suggest that *Ruppia maritima* may provide important habitat for small forage fishes inhabiting lower-salinity areas (Garcia and Vierira 1997, Duffy and Baltz 1998, Castillo-Rivera et al. (2002, 2005). Moreover, Rutherford et al. (1986) demonstrated higher densities of juvenile snook in areas of western ENP estuaries dominated by *Chara* sp., *Ruppia maritima*, and other low-salinity vegetation. Ley (1992) found high densities of fishes and foraging water birds in transition zone of the southeast Everglades, with dense *Ruppia* and associated macroalgae. As this SAV disappeared during the 1989-1990 drought period (when salinity rose well over 50 psu in the mangrove transition zone ponds and creeks), the fish community became depleted and resulted in fewer water birds foraging in these areas. These results support that *Ruppia* and other transition zone SAV provide an important habitat function for the fish and avian community of northeastern Florida Bay.

The food web of transition zone ponds and creeks also supports the endangered American crocodile (Kushlan and Mazzotti 1989, Mazzotti 1999), which in the United States is limited in distribution to the southern tip of Florida and the upper Florida Keys. Crocodile habitat once extended from central Florida southward, but now more than two-thirds of the nests of this federally listed endangered species are found along the Florida Bay coast (USFWS 1998). The area comprising the northeast coast of Florida Bay and transition zone has been designated by ENP as a crocodile refuge, in order to protect these nests. Crocodile nesting success or failure is related to factors such as flooding, desiccation, salinity and predation (Mazzotti 1989, USFWS 1998). The critical time for hatchlings is from late summer through fall, a period in which the historic system delivered greater volumes of fresh water into areas of crocodile habitat (McIvor et al. 1994). Hatchling crocodiles have higher relative metabolic demands and less ability to osmoregulate than do their adult counterparts. Seeking fresh water can be energetically expensive for young crocodiles. Salinity greater than 20 psu in nearshore nesting areas is considered detrimental to the growth and survivorship of young-of-year crocodiles (Mazzotti et al.

1986, Moler 1991, USFWS 1998). In addition, spatial and temporal extension of low-salinity conditions could increase forage fish density and biomass Lorenz (1999). Increasing the forage base (such as transition zone fishes) for pre-adult crocodiles may increase crocodile growth and survivorship in nursery areas around Florida Bay (Mazzotti, personal communication).

Background and Evaluation of the Literature

The transition zone vegetation complex of Florida Bay is important to fauna as a food source and as refuge, supporting a number of faunal species that inhabit the zone either transiently or as resident species (Ley and McIvor 2002, Lorenz et al. 2002). These plants also perform important ecosystem functions outside of the transition zone, supplying detritus for export to the greater estuary, thereby supporting the provision of food for other nekton (Zieman 1982, Snedaker 1989). Primary production in the brackish transition zone also provides a source of dissolved organic compounds distributed within the zone and into Florida Bay, potentially supporting a microbial based food web (Snedaker 1989, Lavrentyev et al. 1998). Furthermore, SAV can sequester nutrients and enhance nutrient retention within the transition zone, which may be important for good water quality in the larger Florida Bay (Rudnick et al. 1999, Davis et al. 2005).

Only a small group of vascular plant and macroalgae species are adapted to grow in the wide-ranging and rapidly changing salinity conditions of the transition zone. Most freshwater plants cannot survive salinity exposure, particularly above mesohaline levels. Likewise, most true seagrasses cannot survive the sustained (several months) freshwater conditions common in the transition zone. If salinity exceeds the tolerance of the few species adapted to this zone, loss of SAV can occur, leaving the benthic habitat as bare, unvegetated substrate (Morrison and Bean 1997, Ley, 1992, Montague et al. 1998).

Submersed vegetation in the ponds and channels of the Florida Bay transition zone has been studied relatively little, usually in localized areas (Montague et al. 1998, Morrison and Bean 1997, Tabb and Manning 1961, Tabb et al. 1962, Zieman 1982). Likewise, the mapping of species composition and distribution across the northern coast of Florida Bay has not been performed comprehensively. Available data show that the vegetation of the transition zone is dominated by characteristic plants common in fresh water and brackish water, including *Chara* spp. (muskgrass, a multicelled macroalga), *Utricularia* spp. (bladderwort), *Ruppia maritima* (widgeon grass, a bushy, fanlike underwater freshwater plant that has a high tolerance for salinity and alkalinity) and *Halodule wrightii* (shoal grass, a seagrass that can withstand a wide range of temperatures and salinity).

A Florida Bay SAV background study for the present report (Battelle 2004) provides information on each of the major vascular SAV species found in the Florida Bay transition zone, including *Ruppia maritima* (widgeon grass) and *Halodule wrightii* (shoal grass) (for additional information on shoal grass, see also Doering et al. 2002).

The vegetation complex of the eastern Bay's salinity transition zone has been monitored by National Audubon Society scientists since 1996, and the coastal Bays of northern Florida Bay (such as Joe Bay and Little Madeira Bay) have been monitored since about 1995 by Miami-DERM, Madden et al. (2003) and the Fish Habitat Assessment Program (FHAP) of the Florida Fish and Wildlife Conservation Commission.

Tabb and Manning (1961) and Tabb et al. (1962) described the biota of northwestern Florida Bay and the Whitewater Bay and Coot Bay region in the 1950s. The salinity transition zone, represented by Coot Bay and eastern Whitewater Bay, was dominated by *Ruppia maritima* (widgeon grass) and *Halodule wrightii* (shoal grass), while northern Florida Bay was dominated by *Thalassia testudinum* (turtle grass) and Halodule. In low-salinity ponds and lakes of the western transition zone, Tabb and Manning (1961) found *Chara* (musk grass) to be predominant where salinity was below 15 psu, while in the more variable salinity of Coot Bay, a distinct zonation occurred, as follows: 1) *Chara* at salinity below 12 psu, 2) *Ruppia* at salinity between 12 and 28 psu and 3) *Halodule* replacing both in areas of salinity greater than 28 psu. The same studies also described the seasonal succession of these plants, indicating that in Coot Bay, *Ruppia* dominated when salinity was below 15 psu but was replaced by *Halodule* during the dry season when salinity rose above 20 psu. During the wet season, both *Ruppia* and *Halodule* were reported to be replaced by *Chara* when salinity fell below 10 psu.

Morrison and Bean (1997) found a similar pattern in ponds of the transition zone of the north-central Florida Bay: *Chara* was found to have an apparent maximum salinity tolerance in the range of 15 to 20 psu. Meanwhile, Montague et al. (1998) studied the transition zone of northeastern Florida Bay and found *Chara* in ponds and streams with a mean salinity of 6 psu, and *Najas* (water nymph) and *Utricularia* (bladderwort) at sites with a mean salinity of 2 psu, observing that both *Najas* and *Utricularia* increased in abundance as the wet season progressed.

Zieman (1982) noted that by the 1980s Florida Bay as a whole was undergoing a shift toward development of monospecific stands of *Thalassia*, with a general loss of *Halodule* and macroalgal species. He attributed this shift to reduction in freshwater inflow and elevation of salinity that had occurred in the previous two decades. Consistent with Tabb and Manning (1961), Zieman (1982) and Zieman et al. (1989) found that *Ruppia* grew well only in areas adjacent to freshwater inflow (Zieman 1982, Zieman et al. 1989). *Ruppia* was generally associated with stands of red mangrove and was located around the fringes of the ecotone in the eastern part of the bay. The vegetation complex in other areas of the northern bay and transition zone of the 1970s and 1980s was described as containing dense stands of *Thalassia* in the coastal bays and equally dense and monotypic stands of Halodule of up to 90 g dw m^{-2} in bays and ponds of the transition zone. Zieman et al. (1989) hypothesized that in the high-light, high-salinity environment created by reduced freshwater input, *Thalassia* thrived at the expense of *Ruppia* and freshwater macroalgae.

The distribution of SAV in Florida Bay has changed during recent decades, probably in response to both natural and human factors. Since the early 1990s, freshwater flow to the Bay has increased, and the somewhat fresher salinity regime in the transition zone has most likely promoted an expansion of the freshwater and brackish-water plant assemblage, with reductions in *Thalassia* coverage in the immediate area of the transition zone (Miami-DERM 2005). Montague et al. (1989) found *Ruppia* to dominate twelve northeastern Florida Bay sites sampled in 1986 that experienced highly variable salinity fluctuations between 0 and 30 psu. *Ruppia* continues to dominate the Florida Bay transition zone as the primary rooted vascular plant, and several freshwater macroalgal species are also abundant in the region, notably *Chara* sp., *Najas* sp. and *Utricularia* sp. (Montague et al. 1989, Montague and Ley 1993, Morrison and Bean 1997, Miami-DERM 2005). The dominant macroalgal species in the transition zone are generally obligately oligohaline or prefer lower salinity and, despite *Ruppia*'s ability to tolerate high salinity, it appears to be outcompeted by true marine seagrasses at even intermediate salinity. In Florida Bay, *Ruppia* and the macroalgal complex are not found in areas seaward of the transition zone.

Overview of *Ruppia maritima*

Ruppia maritima, commonly known as widgeon (or wigeon) grass, is distributed worldwide, occurring in temperate and subtropical estuaries, bays and lagoons and in inland saline lakes and wetlands. This angiosperm is recognized worldwide as an important food of migrant and wintering shorebirds, wading birds and waterfowl and is heavily used by fish in coastal wetlands (Kantrud 1991). Propagation and management of *Ruppia* have occurred for nearly 60 years in the southern and eastern United States, and comprehensive studies and literature reviews are available (Kantrud 1991 and references contained therein, Tyler-Walter 2001 and references contained therein). *Ruppia* has a well-defined ecologic niche. It grows poorly in water with low water clarity or anaerobic sediments, but has specialized features enabling survival under a wide range of salinity and high temperatures beyond those tolerated by most other submersed angiosperms (Kantrud 1991).

Ruppia maritima serves many ecologic functions for a variety of organisms. The leaves and stems of *Ruppia* provide substratum and refuge for several species, and the rhizome and root system stabilize the sediment, transport oxygen from the leaves and oxygenate the sediment in the vicinity of the roots, changing the soil redox potential, sediment chemistry and oxygen levels (Verhoeven and van Vierssen 1978). The decomposition of *Ruppia maritima* leaves and stems supports a detrital food chain within this habitat, especially in temperate regions during autumn and winter. Suspension feeders and bottom feeders such as bryozoans, polychaetes, amphipods, bivalves and chironomid larvae may utilize the detritus produced from the decomposition of *Ruppia* leaves (Tyler-Walters 2001). Verhoeven and van Vierssen (1978) and Verhoeven (1980b) suggested that isopods and amphipods may feed directly on this plant. But *Ruppia*'s most important role in the food chain is the breaking down of decomposed leaves into fine particles of detritus suitable for suspension and incorporation into the detrital food chain (Verhoeven and van Vierssen 1978, Zieman et al. 1984, Harrigan et al. 1989, Kantrud 1991). The leaves of *Ruppia* are commonly colonized by diatoms and other epiphytes and commonly combine with floating mats of filamentous green algae (such as *Cladophora*) and *Chara*. The epiphytes and algal mats of *Ruppia* may be grazed by gastropods, amphipods, isopods and mysids (Tyler-Walters 2001). Faunal epibionts such as bryozoans and hydroids colonize *Ruppia* leaves and also may provide temporary substratum for juvenile anemones and bivalves and the larvae and pupae of aquatic insects (Verhoeven and van Vierssen 1978, Verhoeven 1980a, Boström and Bonsdorf 2000). Other organisms use *Ruppia* beds as habitat and shelter from predation. Small invertebrates are preyed on by mysids, shrimp and forage fish that utilize *Ruppia* habitat (Tyler-Walters 2001). Epifauna, small shallow infauna and larger infauna are probably the most common foods for fish (Harrigan et al. 1989, Montague et al. 1989). Specific studies regarding the epifaunal assemblages within the northeastern Everglades–Florida Bay transition zone are very limited, but Montague et al. (1989) conducted studies that indicated the importance of epifauna associated with the leaves and stems of submersed vegetation within this area. These researchers found a strong correlation of vegetation and benthic infauna in the ponds of the northeastern transitional zone. They could not definitively state, however, whether this correlation was related to the enhanced presence of food and cover that the SAV provide or related independently to the salinity variation causing low densities of both SAV and benthic infauna.

Distribution of *Ruppia maritima* in Relation to Salinity

Studies of the natural history of *Ruppia maritima* suggest the species to be not a true seagrass but a freshwater species unusually tolerant of salinity (McMillan 1974, Verhoeven 1975). Among estuaries worldwide, the species is found in salinity ranging from zero to full-strength seawater, although it is typically distributed and grows most rapidly where salinity is below 25 psu (Phillips 1960). The species commonly dominates in the brackish region of estuaries (Kantrud 1991) and appears to disappear from environments that change from low salinity to marine conditions (Murphy et al. 2003). Exceptions have been observed. The species is also common in saline inland lakes (for instance, in prairie potholes of interior North America), at much higher salinity (>100 g/L) in these environments than is typical in estuarine and marine environments (Kantrud 1991), and it grows within Florida Power and Light's Turkey Point cooling canals where salinity is around 60 psu.

Ruppia populations have been studied in Texas, North Carolina and several locations in Florida, including Apalachee Bay, the Econfina River, Tampa Bay and Florida Bay (Battelle 2004). Populations are generally observed is salinity averaging from 10 to 30 psu, although many of these areas experience variable salinity, and it is difficult to know the salinity range actually encountered by plants in the field. Phillips (1960) found that *Ruppia maritima* occurred below 25 psu in Tampa Bay. Iverson and Bittaker (1986) surveyed stations in river mouths of the Florida west coast over six years and found *Ruppia* to be prevalent in low-salinity areas. Koch and

Dawes (1991) harvested plants in western Florida at salinity ranging from 2 to 14 psu and in North Carolina at salinity between 6 and 30 psu. These reported salinity ranges for *Ruppia* are similar to those found in Florida Bay and Whitewater Bay.

Ruppia maritima Population Dynamics in Relation to Salinity

The aforementioned *Ruppia* distribution patterns reflect the net effects of salinity and other factors on the growth, reproduction and mortality of *Ruppia* populations. An important distinction in plant ecology is 1) a population's physiological tolerance to salinity and 2) the population's actual distribution over a range of salinity in nature. The difference between the two may be attributable to reproductive failure, predation, disease, nutrient resource limitation or other similar factors and stresses. Studies in laboratories have attempted to ascertain exact salinity tolerances of *Ruppia* in mesocosms, and most have found that plants can tolerate very high salinity for limited periods. Lazar and Dawes (1991) found that plants from a Tampa Bay population survived well when exposed to 35 psu in mesocosms, and Koch and Durako (2004) found tolerance of adult plants up to 70 psu in mesocosm studies over a four-month period. In laboratory incubations, Murphy et al. [2003] found a significant depression in *Ruppia* photosynthesis at 40 psu, but these were short-term experiments and the plants may not have acclimated to experimental conditions.

The optimal salinity for *Ruppia* growth appears to be less than 20 psu (Kantrud 1991), but studies of populations in Florida Bay and in other areas indicate that established *Ruppia* plants can tolerate higher salinity and even hypersalinity for extended periods. A factor that may increase *Ruppia* mortality is not simply the magnitude of salinity but the rate of change of salinity. In creeks and small ponds of the Florida Bay transition zone, where salinity can drop very rapidly, Montague and Ley (1993) found that SAV biomass was more closely correlated with salinity variance than with salinity magnitude. Rapid fluctuations have also been reported to kill *Ruppia* when salinity rose > 18 g/L in a few weeks (Verhoeven 1979).

The collective evidence on the relationship between *Ruppia* reproduction and salinity points toward the impact of the magnitude, timing and duration of high-salinity events (marine and hypersaline) on Ruppia populations, in part perhaps because the seeds appear to be sensitive to salinity levels. Dunton (1990) found that *Ruppia* populations in two different Texas lagoons ranging in salinity from 0 to 25 psu and 32 to 38 psu were equally productive; however, the population at the high-salinity site in the Nueces River had an overwintering form, while the low-salinity site population in the Guadalupe Estuary did not. These observations suggested that *Ruppia* seeds may be sensitive to high salinity, requiring the plants to propagate vegetatively at the high-salinity site.

Ruppia seeds generally overwinter for one season before germinating the following spring (Phillips 1960); therefore, the spring-summer period of germination and seedling development may represent a period during which the appropriate salinity regime is especially important. It is not known if periods of high salinity kill seeds (likely not), nor is the length of time seeds remain viable in sediments well known (probably between one year [Hanlon and Voss 1975] and three years [Kantrud 1991]). But perhaps the most important reason that *Ruppia* populations are uncommon in estuarine areas with salinity frequently above 30 psu is reproductive failure. Flowering, and hence seed production, is reported to occur only at salinity below 30 psu (Kantrud 1991), a finding consistent with the observations made on Florida's west coast by Iverson and Bittaker (1986). Germination of *Ruppia maritima* seeds has been reported to be greatly reduced where surface sediments contain more than 20 g/L soluble salts or where sodium chloride concentrations in the water exceed 15 g/L (Kantrud 1991).

Interactive Effects of Salinity and Other Factors on *Ruppia maritima*

Site-specific differences may also be important for *Ruppia maritima* germination. In laboratory work, Koch and Dawes (1991) found germination differences in seeds obtained from estuaries in North Carolina versus seeds obtained from estuaries in Florida. Seeds obtained from Pamlico Sound, North Carolina, had an earlier germination time (25 days) in fresh water and a significantly higher germination rate at all salinity tested (0, 15, 30 psu) as compared with the seeds from the Weeki Wachee River, Florida (germination time = 35 days in fresh water). Germination of the Florida seeds was time delayed even further (> 30 to 68 days) and less than three percent successful at 15 psu and did not occur at all at 30 psu (80 seeds used per treatment).

Water temperature and seasonal temperature fluctuations also influence reproductive success (particularly germination) and may be important considerations in *Ruppia maritima* reestablishment, particularly in environments with widely fluctuating or high salinity. Harrison (1982) found that seedling success differs from year to year, especially in response to variations in conditions (weather) in early spring, when germination and establishment occur. Seeliger et al. (1984) hypothesize that optimal germination conditions for *Ruppia* vary from latitude to latitude because of temperature differences. Kantrud (1991) provides a comprehensive discussion of germination and growth potential of Ruppia in mild climates and suggests that temperature plays a role in the life strategy of the species, noting that germination rates of seeds are higher for those kept at lower temperatures in waters where salinity ranges up to 26 g/L than for those kept at higher temperatures in fresher (< 3.5 g/l) waters.

In work comparing seeds from a Florida estuary (mild seasonal water temperature fluctuations) with seeds from a North Carolina estuary (higher seasonal fluctuations), Koch and Dawes (1991) found differences in germination over a range of temperatures tested (salinity of 0 psu). The North Carolina seeds exhibited a significantly higher rate and number of germinations than did the Florida seeds at all temperatures tested (17, 23 and 29^{o} C). The authors suggest that the smaller seasonal fluctuation in temperature in Florida, with favorable temperatures for growth throughout the year, may account for the slower germination rate of seeds from that area. In contrast, the North Carolina seeds may be adapted to take advantage of a much shorter growing season. Further illustrating the importance of considering temperature in milder climates in combination with higher salinity fluctuation, Seeliger et al. (1984), in work using seeds obtained from Patos Lagoon estuary in southern Brazil, found that the best germination response (> 10 percent) was obtained at lower salinity (< 20 psu) and after 12 months of cold storage (7^{o} C). Water temperatures do not normally get very low in the Everglades–Florida Bay transition zone, but the North Carolina and the Brazil studies both indicate that exposure to the combination of lower water temperatures and low salinity may be important for successful germination. Given the climate in southern Florida, fairly low germination rates throughout the year for *Ruppia maritima* would be expected in a brackish environment such as the transition zone, and reestablishment from seeds after a significant stress (such as a hypersaline period) may be precluded or delayed because of the combination of salinity and relatively high temperature.

Some field evidence also indicates that reestablishment of *Ruppia* in the Everglades–Florida Bay transition zone may be negatively affected by high temperature and high salinity. In the course of a two-year field study, Montague et al. (1989) observed that relatively dense *Ruppia*-dominated vegetation disappeared in a pond along Snook Creek (a small tributary to Joe Bay, which is a northeastern embayment of Florida Bay). SAV had been abundant in March through May of 1986 but disappeared thereafter for the remainder of the study period (through September 1987). Salinity rose at this site in March through May from 13 ppt to 26 ppt and by June had dropped to 1 ppt, where it remained until August of that same year. Dense mats of the filamentous blue-green alga *Lyngbya* appeared in Snook Creek following the disappearance of the macrophytes (including *Ruppia*); SAV was no longer observed for the duration of the study period. The researchers cited either high salinity, salinity shock (a sudden salinity drop) or a combination of the two as the most likely cause. This observation illustrates potential difficulties in the

Everglades–Florida Bay transition zone with regard to reestablishment of vegetation after that vegetation's demise. Apparently, for an entire year thereafter, two months of low salinity in the summer months was not sufficient time or condition for any SAV, including *Ruppia maritima*, to become reestablished in this pond area. This finding suggests that once SAV has disappeared, a sufficient duration of a low salinity conditions with appropriate seasonal timing (temperature) must be maintained the Everglades–Florida Bay transition zone in order to promote reestablishment.

Another interactive factor that potentially influences reproductive success is dissolved-oxygen availability, which varies as a function of temperature and salinity. Kantrud (1991) reported that oxygen scarcity, as indicated by a redox potential of -300 mV, retards germination. Senescence and loss of stems seems to coincide with increases in hydrogen sulfide in the sediment and may be a factor that helps explain decreased germination in hot summer months when sulfate reduction rates (and hence the production of hydrogen sulfide) are likely to peak. The saline ponds of the transition zone typically contain sediments with high concentrations of organic matter (>10 percent of dry weight) and low concentrations of iron, resulting in high sulfide concentrations (Koch et al. 2001).

Laboratory Analysis

Salinity's effects on *Ruppia maritima* were examined in Florida Bay and the Florida Bay transition zone using a combination of controlled laboratory studies and field data. Mesocosm experiments were conducted to test the response of *Ruppia* to salinity and temperature (Koch and Durako 2004); effects on adult plant growth and survivorship, as well as on seed germination and seedling development, were measured. Results showed that in the mesocosm, adult *Ruppia* plants tolerated salinity as high as 70 psu for up to four months. However, this result was inconsistent with maximum salinity at locations where *Ruppia* is observed in the transition zone, suggesting that in the field, *Ruppia* distribution is not a simple function of adult plant salinity tolerance. Additional important controls on distribution may include nutrient limitation, thermal stress, light limitations, substrate incompatibility, disease and grazing, at higher salinity. These factors may act as controls independently or in concert with salinity.

One line of evidence that may explain the confinement of *Ruppia* beds to areas of lower salinity (less than 25–30 psu) is shown in studies of seed germination at different salinity; a laboratory germination study using *Ruppia maritima* seeds from Florida Bay (Koch and Durako 2004) showed that seed germination is inhibited at salinity above intermediate levels (**Figure 33**). Approximately one-third of the seeds that were incubated at low to intermediate salinity successfully germinated, but germination did not occur at any salinity treatment higher than 30 psu, even when salinity was slowly increased to allow time for acclimation. Without slow acclimation, germination did not occur at salinity higher than 20 psu. This outcome is consistent with results from an earlier germination experiment by Koch and Dawes (1991), who found lower rates of germination at 15 psu than in fresh water and no seed germination at all at 30 psu. Sustaining a plant population requires not only that adults can physiologically tolerate the environment but also that they can successfully reproduce in that environment.

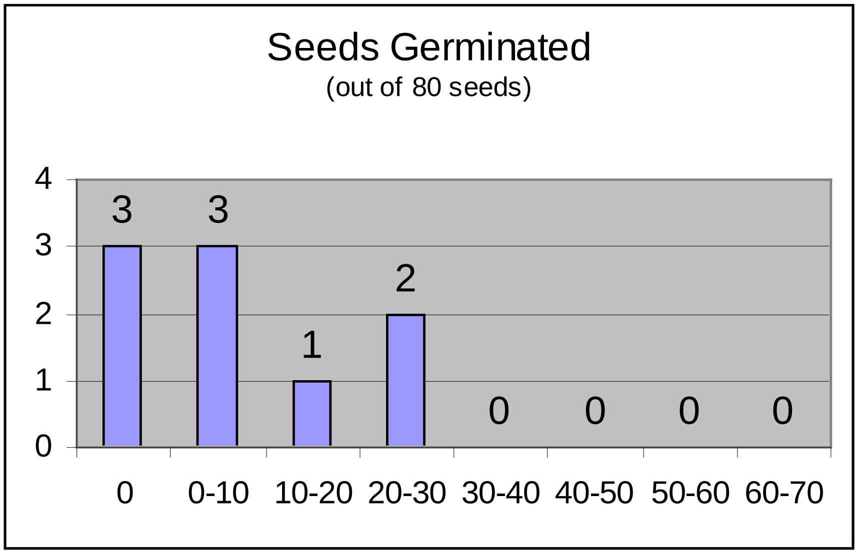


Figure 33. Salinity's Effect on *Ruppia maritima* Seed Germination. Number of seeds germinated (out of 10 seeds per treatment) during four-month incubations. Eighty seeds were incubated in eight salinity classes in the experiment (Koch and Durako 2004).

Analysis of Field Data

Field data from the 1996–2004 period (National Audubon Society, Frezza and Lorenz, unpublished) show that percentage cover by *Ruppia maritima* decreases with increasing salinity in Florida Bay. Ruppia as was dominant cover, but declined significantly ($p < 0.001$ from analysis of variance [ANOVA]) in waters above 25 psu. Data were collected along three transects through the transition zone and into the Bay: 1) Taylor River into Little Madeira Bay, 2) from a creek that flows into northeastern of Joe Bay, through Joe Bay, and into Trout Cove and 3) along Highway Creek flowing into Long Sound (**Figure 34** and **Figure 35**). The first transect (Taylor River to Little Madeira Bay) corresponds to the representative transition zone gradient described in this report. Salinity varies more rapidly than plants can respond in terms of cover, and so *Ruppia* cover was also compared with the average salinity during the 30 days prior to the day of the sample, with virtually the same results.

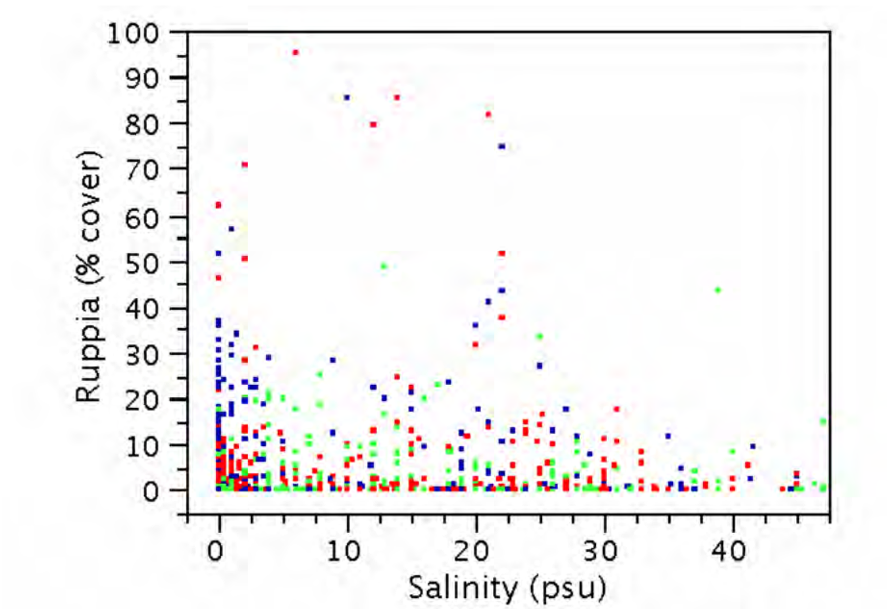


Figure 34. *Ruppia maritima* Cover in Relation to Corresponding Instantaneous Salinity in the Everglades–Florida Bay Transition Zone. blue = Taylor River transect (corresponds to the representative transition zone gradient described in this report – see **Figure 23**), red = Joe Bay transect, green = Highway Creek transect) Data from National Audubon Society, Frezza and Lorenz (unpublished).

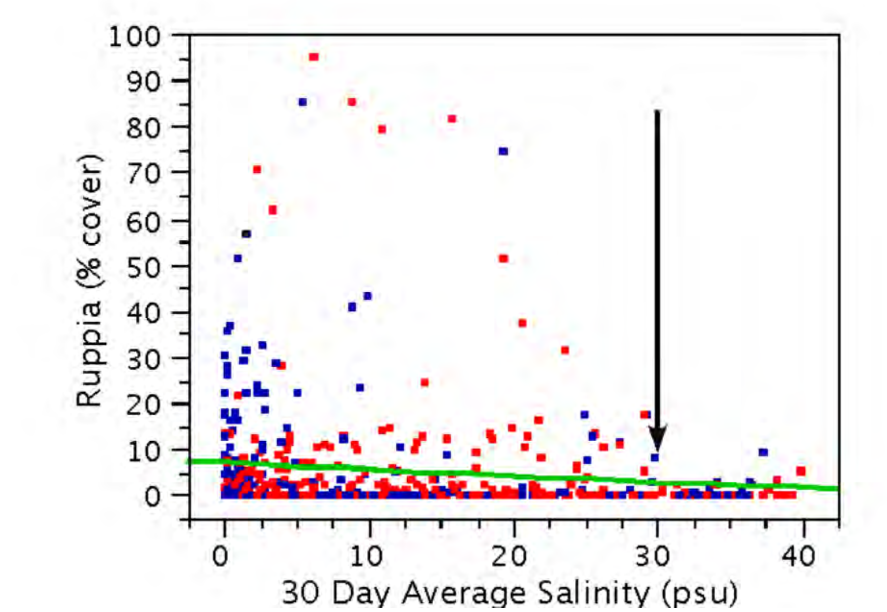


Figure 35. *Ruppia maritima* Cover in Relation to Corresponding 30-Day Average Salinity in the Transition Zone. Data shown were extrapolated from continuous monitoring data for the Florida Bay–Everglades transition zone; arrow points to 30 psu level, where *Ruppia maritima* cover decreases to below 5 percent; green line is regressed trend line that indicates decreasing *Ruppia maritima* cover with increasing salinity (p=0.0084, 1.d.f); blue = Taylor River transect; red = Joe Bay transect. Data from National Audubon Society, Frezza and Lorenz (unpublished].

To estimate average 30-day salinity, instantaneous salinity measurements at *Ruppia* sampling sites were extrapolated using regressions of salinity measured at the SAV sites against daily salinity measurements recorded at the nearest SFWMD, ENP and USGS continuous-monitoring platforms (**0** A trend line through the relationship between average salinity and *Ruppia maritima* cover suggests that average cover decreases with salinity (p=0.008, 1 df) (**0** The 30-day salinity data were also grouped into several discrete categories— 0–10 psu, 10–20 psu, 20–30 psu and >30 psu—and were compared with corresponding SAV cover. The 0–10 psu category exhibited the highest percentage of cover, and the mean cover decreased with each increasing salinity range. ANOVA showed that the cover means were statistically different (p=0.0272, with 3 df) for each category, and a pair-wise t-test identified that the >30 psu category was significantly lower than the 0–10 psu category ($p < 0.05$). In summary, *Ruppia maritima* cover appears to be significantly reduced at salinity above an average of 30 psu.

Table 11. Regression equations used to calculate 30-day average salinity values in the transition zone. Equations were developed for each of the National Audubon Society sites along the Taylor River and Joe Bay transects. Daily mean salinity results used for the extrapolations were obtained were from the ENP Argyle Henry (ENP-AH), USGS Taylor River ([USGS-TM), and the SFWMD Joe Bay (SFWMD-JB) platforms; for each site, instantaneous salinity data were regressed against the daily salinity measurement from the associated platform to create the extrapolation equations.

Station	Platform (Agency-Site)	Extrapolation Equation	R^2
TR1	ENP-AH	TR1 = -0.446+0.972*AH	0.967
TR2	ENP-AH	TR2 = -0.342+0.984*AH	0.976
TR3	ENP-AH	TR3 = -4.201+6.240*Sqrt(AH)	0.964
TR4	ENP-AH	TR4 = -3.573+6.429*Sqrt(AH)	0.955
TR5	ENP-AH	TR5 = -2.186+6.284*Sqrt(AH)	0.938
TR6	USGS-TM	TR6 = 5.922+0.832*Sqrt(TM)	0.912
JB1	SFWMD-JB	JB1 = -0.556+0.028*JB^2	0.848
JB2	SFWMD-JB	JB2 = 0.695+0.027*JB^2	0.850
JB3	SFWMD-JB	JB3 = -1.221+0.929*JB	0.910
JB4	SFWMD-JB	JB4 = 0.304+1.001*JB	0.907
JB5	SFWMD-JB	JB5 = 3.479+0.964*JB	0.856
JB6	SFWMD-JB	JB6 = 6.475+0.851*JB	0.806

Similar patterns of SAV cover and salinity were observed for the macroalga *Chara* (muskgrass), with an apparent salinity threshold near 30 psu (**Figure 36**). Patterns for two other common macroalgae, *Najas* (water nymph) and *Utricularia* (bladderwort) indicated a lower salinity tolerance. Little cover was found above 15 psu (**Figure 37** and **Figure 38**).

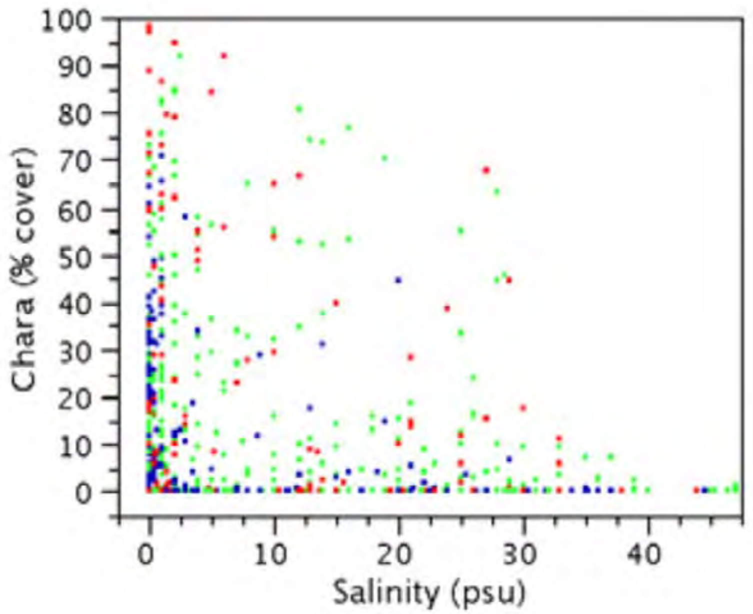


Figure 36. *Chara* (Muskgrass) Cover in Relation to Instantaneous Salinity in the Transition Zone. Blue = Taylor River transect (corresponds to the representative transition zone gradient described in this report [see Figure 23]); red = Joe Bay transect; green = Highway Creek transect. Data from National Audubon Society, Frezza and Lorenz (unpublished).

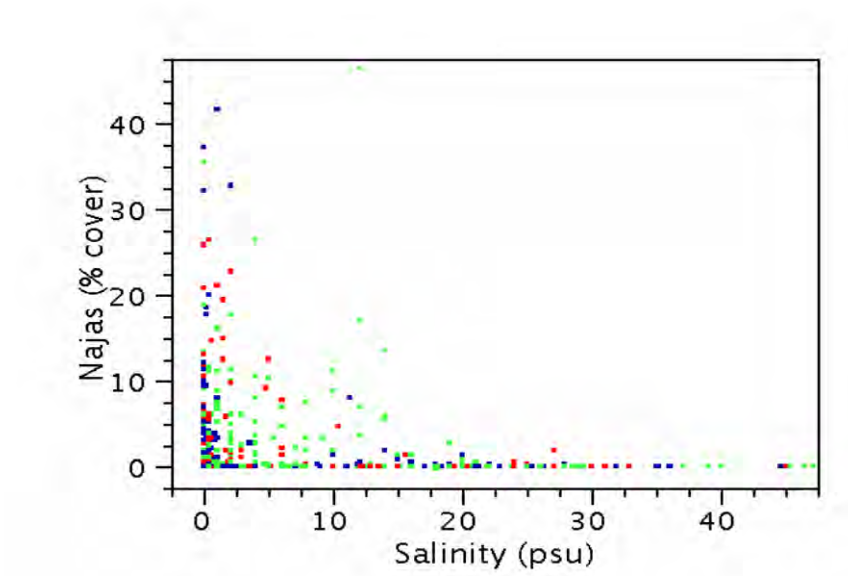


Figure 37. *Najas* (water nymph) Cover in Relation to Instantaneous Salinity in the Transition Zone. Blue = Taylor River transect; red = Joe Bay transect; green = Highway Creek transect. Data from National Audubon Society, Frezza and Lorenz (unpublished).

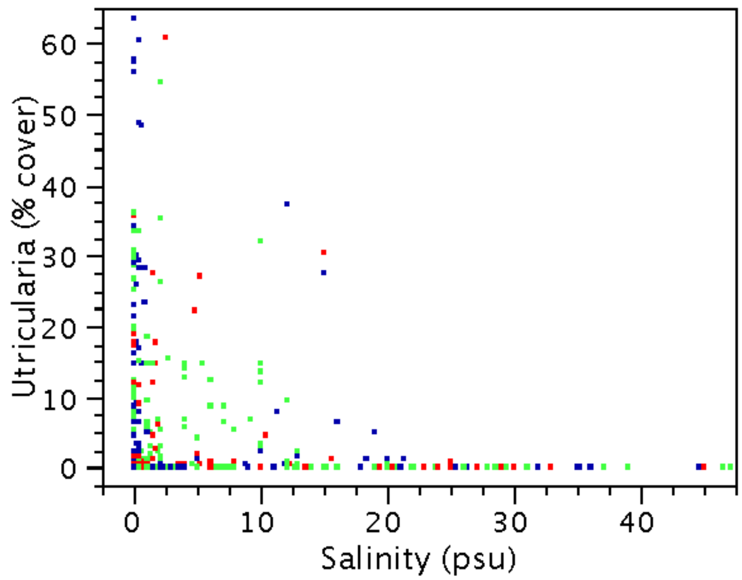


Figure 38. *Utricularia* (Bladderwort) Cover in Relation to Instantaneous Salinity in the Transition Zone. Blue = Taylor River transect; red = Joe Bay transect; green = Highway Creek transect. Data from National Audubon Society, Frezza and Lorenz (unpublished).

SAV of the Transition Zone: Summary

Several lines of evidence from Florida Bay and other estuaries indicate that *Ruppia maritima* (widgeon grass) fills an important niche in the highly variable oligohaline-mesohaline region of estuaries. Throughout Florida, the southeastern United States and the U.S. Gulf coast, *Ruppia maritima* populations typically inhabit areas where salinity ranges from 0 to about 30 psu. An apparent inhibition of population growth at salinity levels above 30 psu is evident from Florida Bay survey results that indicate decreased areal coverage by *Ruppia* during periods of drought and elevated salinity. Preliminary statistical analysis of *Ruppia* distribution suggests an upper salinity limit of 25 or 30 psu for viable populations. While laboratory studies have found that *Ruppia* can tolerate high hypersalinity when other environmental factors are favorable, the absence of *Ruppia* at field sites under hypersaline conditions may indicate the importance of the interaction of salinity with other factors.

Hypersalinity may cause the long-term (mullet-year) loss of *Ruppia* from transition zone sites because of reproductive failure. Laboratory study of seed germination indicated that no recruitment occurs above 30 psu. Additionally, field observations were that no flowering occurs above 30 psu, pointing to a mechanism by which *Ruppia* populations are effectively confined to the mesohaline reach of estuarine systems. For Florida Bay, in order for local *Ruppia maritima* populations to reproduce successfully and be sustained, it appears that salinity must be below a threshold of about 30 psu when seeds are germinating and when seedlings are emerging.

Ruppia represents the best available candidate for an indicator species in the transition zone because of its ecologic importance and its role as the dominant rooted vascular macrophyte. The presence and condition of *Ruppia* at a site also provides an indication of pre-existing salinity conditions. In addition, the response of *Ruppia* to high salinity also closely tracks the responses of other important species that inhabit the mangrove transition zone, including *Chara* (muskgrass), *Najas* (water nymph) and *Utricularia* (bladderwort). *Ruppia* and *Chara* distribution and cover are fairly sensitive to salinity, greatly decreasing between 25 psu and 30 psu. *Utricularia* and *Najas* are significantly less salinity tolerant, with salinity thresholds at around 15 psu. This relationship places *Ruppia* at the upper limit of salinity tolerance for maintaining the low-salinity macrophyte assemblage and SAV habitat of the transition zone. When *Ruppia* is impaired by excessive salinity, the freshwater/mesohaline macroalgae consortium is most likely already impaired or eliminated. If *Ruppia* is eliminated because of high salinity, the entire vegetation association characteristic of the transition zone, along with its habitat function, is probably also gone. Disappearance of *Ruppia* and the associated algal species from the northern coastal bays would be harmful to the low-salinity fauna of the transition zone that depend on this vegetation assemblage, other low-salinity SAV and macroalgae for food and cover.

Northeastern Florida Bay and Its Submersed Aquatic Vegetation

A defining feature of the northeastern zone of Florida Bay, as of the Bay as a whole, is its shallowness: the water of the northeastern zone averages about 1 meter in depth (Schomer and Drew 1982). As a result, sunlight sufficient to support photosynthesis can reach the sediment surface in almost all parts of the northeastern Bay, resulting in dominance of seagrass beds as both a habitat and a source of primary production. This shallowness, combined with meager water exchange between the northeastern zone and the Atlantic Ocean or Gulf of Mexico (because of central and western Bay mud banks), results also in long residence times and the potential for hypersalinity during droughts, as described in the earlier section on Bay hydrology. Another defining feature of the northeastern Bay is that phosphorus concentrations are extremely low: primary productivity is strongly phosphorus limited (Boyer et al. 1997, Childers et al. 2005).

The foundation of the Florida Bay ecosystem is its seagrass community (Zieman et al. 1989, Fourqurean and Robblee 1999, Rudnick et al. 2005). In the northeastern Bay, both *Halodule wrightii* (shoal grass) and *Thalassia testudinum* (turtle grass) are common, with the *Halodule* being more common in less saline (often mesohaline–polyhaline) waters near the northern shoreline. Seagrasses are a highly productive foundation of the food web, a principal habitat for higher trophic levels and a controller of water quality, which they affect through 1) nutrient uptake and storage, 2) trapping of particles (within their leaf canopy) and 3) binding of sediments (with their roots). With growth of dense seagrass beds, these three water quality control mechanisms drive the Bay toward a condition of clear water, with low nutrient availability for phytoplankton growth and low concentrations of suspended sediment in the water. Nearshore regions of northeastern Florida Bay, such as Little Madeira Bay) tend to have dense seagrass beds, but much of the remaining northeastern Bay has relatively shallow sediments (depth to the limestone base), low phosphorus availability, relatively sparse seagrass coverage (compared with central and western Florida Bay) and high turbidity from suspended sediments (Stumpf et al. 1999).

Seagrasses provide refuge, spawning or nursery area and a food source for numerous important fish and invertebrate species (Zieman 1982, Sogard et al. 1989, McIvor et al. 1994, Thayer et al. 1999, Heck et al. 2003). Faunal growth, survival and abundance tend to be greater in the seagrass beds than outside the beds (Heck et al. 2003). Spotted sea trout (*Cynoscion nebulosus*), grey snapper (*Lutjanus griseus*), red drum (*Sciaenops ocellatus*), snook (*Centropomus undecimalis*), striped mullet (*Mugil cephalus*), bay anchovy (*Anchoa mitchelli*) and a variety of forage fishes are permanently or transiently resident in Florida Bay (Sogard et al. 1989, Johnson et al. 2004). Pink shrimp (*Penaeus duorarum*) and the spiny lobster (*Panulirus argus*) use much of Florida Bay as a primary nursery ground (Browder et al. 1999, Butler et al. 1995). Shrimp develop in the Bay, favoring seagrass habitat, before migrating to the Dry Tortugas (Ehrhardt and Legault 1999). Lobsters use the Bay as juveniles before emigrating across the Keys to the Reef Tract offshore (Davis and Dodrill 1989).

Most of the taxa of the popular game species and forage base species described in Chapter 2 have been collected Baywide, with the abundance of the individual species varying from zone to zone (in relative and absolute terms). The northeastern zone of the Bay supports relatively low abundances, variously attributed to the zone’s comparatively lower primary productivity, its reduced circulation and tidal range, its geographic isolation (lack of marine connectivity for offshore spawners) and its increased variability of salinity (Montague and Ley 1993, Ley et al. 1999, Browder et al. 2002). Moreover, some surveys (as described by Ley et al. 1999, Matheson et al. 1999, Browder et al. 2002, Powell 2003 and Johnson et al. 2004) do not support the idea that the northeastern Bay zone functions as a significant estuarine nursery for important game and commercial fisheries.

These conclusions require important caveats. For instance, over recent decades, the northeast zone has been the subject of fewer faunal surveys than have other zones of the Bay (Tabb et al. 1962, Thayer and Chester 1989, Powell et al. 1989, Sogard et al. 1989a and 1989b, Matheson et al. 1999, Thayer et al. 1999). Furthermore, perhaps one of the most thorough fish surveys specific to the northeast zone (as described in Ley et al. 1999) was conducted during a historic drought when the entire Bay experienced prolonged hypersaline concentrations. Work that has included the northeast zone (described and used by Johnson et al. 2005) has captured significant numbers of forage fishes, especially in the families Engraulidae (anchovies), Cyprinodontidae (killifish), Syngnathidae (pipefish), Gerreidae (mojarras) and Gobiidae (gobies). These smaller forage species compose a majority of the northeast system's fish abundance and biomass, and these same species are also broadly distributed across the Bay—facts that facilitated these particular fishes' use in the forage model, which are discussed later in this document.

The mobility of many of Florida Bay's fishes also indicates the importance of understanding hydrologic and hydrodynamic connections between the Everglades watershed and all regions of the Bay. A literature review by Johnson et al. (2004) emphasized that all five species examined (bay anchovy, snook, spotted sea trout, grey snapper and pink shrimp) would benefit from a reduction in the coverage, intensity and duration of hypersaline conditions in the Bay, especially during the summer and late fall, when salinity-sensitive, post-larval life stages are most abundant. Prolonged hypersalinity is less common in the northeast region, but the insufficiency of hydrologic and hydrodynamic modeling tools inhibits understanding and prediction of how such conditions are established in adjacent interior portions of the Bay. Moreover, the review by Johnson et al. (2004) reinforced the importance of examining habitat quality beyond salinity effects, especially in terms of SAV density and type.

Background and Evaluation of the Literature

The seagrass community is involved in nearly every habitat and every trophic and physico-chemical function of Florida Bay's ecology and plays an extremely important role throughout the Bay's ecosystem (Stumpf et al. 1999, Matheson et al. 1999, Fourqurean et al. 2002, Ley and McIvor 2002). This seagrass community is extensive, with a range that comprises virtually the entire Bay, making it "one of the largest seagrass resources on earth" (Zieman 1982). Florida Bay seagrasses have been subjected to perturbations that have altered their productivity and composition, leading to a catastrophic die-off in 1987 (Robblee et al. 1991); even today they continue to exhibit impairment (Hall et al. 1999, Durako et al. 2002).

Despite their importance, seagrasses in Florida Bay were not systematically monitored prior to the 1980s and only fragmented information exists regarding seagrass ecology and environmental conditions of Florida Bay prior to that time. Tabb et al. (1962) qualitatively described the extensive seagrass community in central and eastern Florida Bay as consisting of mixed stands of *Thalassia testudinum* (turtle grass) and *Halodule wrightii* (shoal grass) or of dense monotypic stands of shoal grass.

Subsequent shifts in seagrass community structure in Florida Bay appear to have occurred in association with changes to Bay hydrology and upstream landscape alterations for water management (Light and Dineen 1994) that were initiated in the early twentieth century and culminated in the 1960s. Historical information is rare, but Zieman (1982) and Zieman et al.

(1999) pieced together information about Florida Bay seagrass community distribution and succession from interviews with local watermen and unpublished reports. The Bay was starved for fresh water for more than a decade during the 1970s, became a clear lagoon and was prone to episodes of hypersalinity. These conditions promoted the increasing dominance of turtle grass in both standing crop and spatial extent and decreased the prevalence of bare patches and shoal grass stands (Zieman 1982) throughout the Bay.

A few years ago, eastern Florida Bay was characterized by nutrient scarcity, thin and shallow sediments and the lowest overall abundance of *Thalassia* in the entire Bay. A 1984 vegetation survey showed the eastern Bay to be mainly comprised of sparse and patchy *Thalassia*, with a standing crop of 0–10 g dry weight m^{-2}, mixed with *Halodule*, which was more prominent in disturbed areas (Zieman et al. 1989). The tops of eastern Bay banks often hosted denser stands of *Thalassia*, with a standing crop of up to 30 g dry weight m^{-2}. The leaves in these stands were often covered with epiphytes. Species of macroalgae of genera such as *Laurencia, Batophora, Acetabularia* and *Penicillus* were found in specialized eastern Bay habitats such as the lee sides of banks and bedrock outcroppings. Meanwhile, in the central Bay, by comparison, dense monospecific stands of *Thalassia* were present, usually on the order of 50–60 g dry weight m^{-2}, but there was little evidence of *Halodule*. The densest stands of Thalassia occurred in western Florida Bay, forming extensive beds of 75–125 g dry weight m^{-2} and up to 400 g dry weight m^{-2} on some bank tops.

Hall et al. (1989) noted that *Halodule* was distributed throughout the entire Bay, with highest short-shoot densities (>1500 shoots m^{-2}) in the western Bay and lowest densities (0–1 shoots m^{-2}) in the southern Bay. The eastern Bay had intermediate densities of *Halodule*, in the range of 0–500 shoots m^{-2}. Montague et al. (1989) characterized the eastern Bay as sparsely vegetated overall (0–600 g dry weight m^{-2}), with *Thalassia* and the alga *Penicillus* in the most saline part (mean of 31 psu), grading to *Halodule* in areas of intermediate salinity (mean of 21 psu) and to *Ruppia, Batophora* and *Chara* at Florida Bay–Everglades transition zone sites (mean of 15 psu).

Seagrass Die-Off and Recent Changes in Florida Bay

Changes in seagrass distribution and density occurred because of a massive *Thalassia* die-off event that began in the fall of 1987 (Robblee et al. 1991, Hall et al. 1999). Die-off was first noted in the north central Bay (in Rankin Lake) and in the southeastern Bay (Robblee et al. 1991). The die-off quickly spread to western Bay basins (Johnson Key basin and Rabbit Key basin) and continued through 1989. This initial event severely affected the SAV community, killing about 4000 hectares of *Thalassia* beds outright and thinning the population in 23,000 additional hectares. Within the major die-off areas, 95 percent of plants were killed and mortality eventually consumed 30 percent of the entire *Thalassia* community in Florida Bay (Hall et al. 1999, Durako et al. 2002). The common factor across die-off sites was the rapid, near-total death of dense stands of *Thalassia*. The central Bay and western Bay sites were most severely impacted. In the western Bay, die-off was practically nonexistent. The northeastern Bay and its less dense stands were not affected by the initial die-off, but the ecosystem-wide impacts may have had indirect implications for this area.

Halodule (shoal grass) and *Syringodium* (manatee grass) were not involved in the initial die-off event (Zieman et al. 1999, Hall et al. 1999), but after primary die-off subsided, a general, slower decline of the seagrass community began, which involved these two species. *Halodule* declined markedly in the years following the die-off from 1989 to 1994 (Durako et al. 2002). *Halodule* and *Syringodium* are thought to have been adversely affected by the secondary effects of the initial die-off, notably by an increase in water column turbidity that began in 1991. This “secondary die-off” may be evidence of the keystone role that *Thalassia* plays in the survival of other benthic flora, as the light penetration characteristics of Bay waters seem to have been altered by the loss of *Thalassia*’s sediment stabilization and nutrient uptake properties.

Seagrass cover continues to change dynamically today. **Figure 39** includes change maps for *Halodule* and *Thalassia* cover in the 1995–2001 and 1995–2003 periods. The circled area is the part of the northeastern Bay covered by this study, located along the gradient through the transition zone, includes Madeira Bay (west of Little Madeira Bay) and includes Eagle Key Basin (south of Little Madeira Bay). Results showed little change (gray shading) in *Halodule* in this region even as significant losses of *Thalassia* occurred there between 1995 and 2001, followed by a strong rebound of *Thalassia* between 2001 and 2003. Meanwhile, in the western Bay, long-term losses in *Thalassia* continued, but increases in *Halodule* were observed.

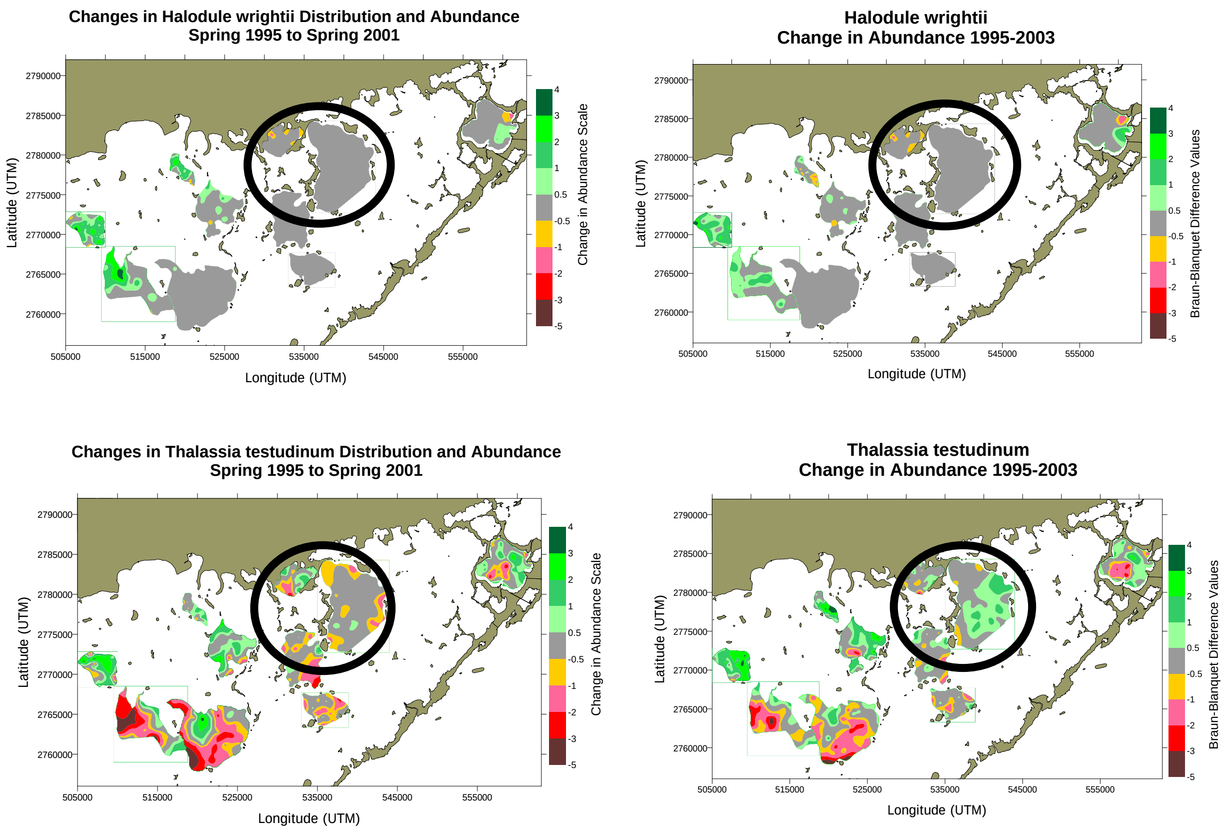


Figure 39. Changes in Florida Bay SAV Cover 1995–2003. Maps show areas of seagrass Braun-Blanquet density 1995–2001 and 1995–2003 for *Halodule* (upper) and *Thalassia* (lower); green tones represent areas of increasing SAV cover over the specified time interval, while red tones represent areas of decreasing SAV cover over these intervals. Circles indicate general region represented by the Everglades-Florida Bay Transition zone transect. Data from FHAP monitoring program, Durako and Hall (unpublished).

Salinity Responses of *Thalassia* and *Halodule*

Analyses of Field Data

Several studies have assessed the salinity tolerance and ranges of *Thalassia* and *Halodule* (reviewed in Battelle 2004). Mesocosm and field measurements indicate that the optimum salinity range for these marine plants is near full-strength seawater. Hanlon and Voss (1975) describe the optimum salinity range for *Thalassia* as 25–38 psu and note the plants' ability to tolerate extremes of 11–48 psu; *Halodule* is noted as tolerant of salinity between 1–60 psu. Zieman (1982) describes the salinity range of *Thalassia* as 28–45, with maximum productivity at 35 psu.

In Florida's Caloosahatchee estuary system, Doering et al. (2002) found densest *Halodule* (>1500 m^{-2}) at salinity above 20 psu. Montague and Ley (1993) found *Thalassia* in Florida Bay at 20–40 psu. In Texas, Jewett-Smith (1991) measured high shoot densities of *Halodule* (5800–15,800 m^{-2}) in Redfish Bay, Nueces Bay and in the hypersaline Laguna Madre (40 psu). Dunton (1996) found healthy populations of *Halodule* in Laguna Madre at salinity up to 55 psu.

Tabb et al. (1962) observed in Florida Bay that *Thalassia* was found two plant forms: a thin and small profile plant in eastern Bay areas subjected to widely fluctuating salinity (25–45 psu) and taller and more robust plant in areas of stable marine salinity. During a drought period ending in 1957, the short population along with a macroalgal assemblage dominated by *Caulerpa* increased in density. When the drought ended and salinity declined in the eastern Bay, *Thalassia* declined in size and density until another drought began in 1961. *Thalassia* reached peak biomass during the second drought year of 1962. Tabb et al. (1962) observed plant die-back in Florida Bay at 45 psu, resulting in bare sediment substrate after 3–5 months.

Seagrass cover, shoot densities of *Thalassia* and *Halodule* were measured in northeast Florida Bay (Little Madeira Bay, Joe Bay and Long Sound) from April 1999 to September 2004 (Miami-Dade Department of Environmental Resource Management or DERM). Densities were compared to instantaneous salinity (**Figure 40**). These salinity data were too sparse to extrapolate 30-day means of salinity prior to sampling. In addition, the highest salinity value observed during the five-year period was about 43 psu, so the effects of more extreme hypersalinity that can occur in the region could not be inferred from these results. The *Halodule* and *Thalassia* density measurements appeared to be independent of the instantaneous salinity measurements, meaning that it is difficult to assign a threshold salinity within this observed range that would be injurious to either species.

When short-shoot data are plotted against water depth (**Figure 41**) the two species have different distributions, with the mode for *Thalassia* around 0.8 m and for *Halodule* around 1.1 m. Even keeping in mind that *Thalassia* is a taller plant, based on these field observations, it appears that *Thalassia* density increases relative to *Halodule* in shallower water. It is difficult to infer causality from this relationship, but one possibility is that colonization by *Thalassia*, which has a higher light requirement than *Halodule* (Zieman 1982), may be favored in shallower water, whereas *Halodule* colonization is favored in slightly deeper and more turbid waters (Kenworthy and Schwarzchild 1995). This and other additional subtle competitive factors make it difficult to differentiate between the two species' salinity tolerances from simple field data. Both tolerate salinity well, but other interrelated background factors are in operation and must be considered. The decline of much of the *Halodule* in the Bay subsequent to the *Thalassia* die-off event made it clear that environmental conditions must be maintained within appropriate ranges in order to support the entire community of seagrass species. The complexities of habitat requirements, including salinity effects, can be adequately understood only through a dynamic multivariate simulation model of seagrass community ecology. This kind of tool provides a means to simultaneously analyze all factors, including hypersalinity that affect the resource

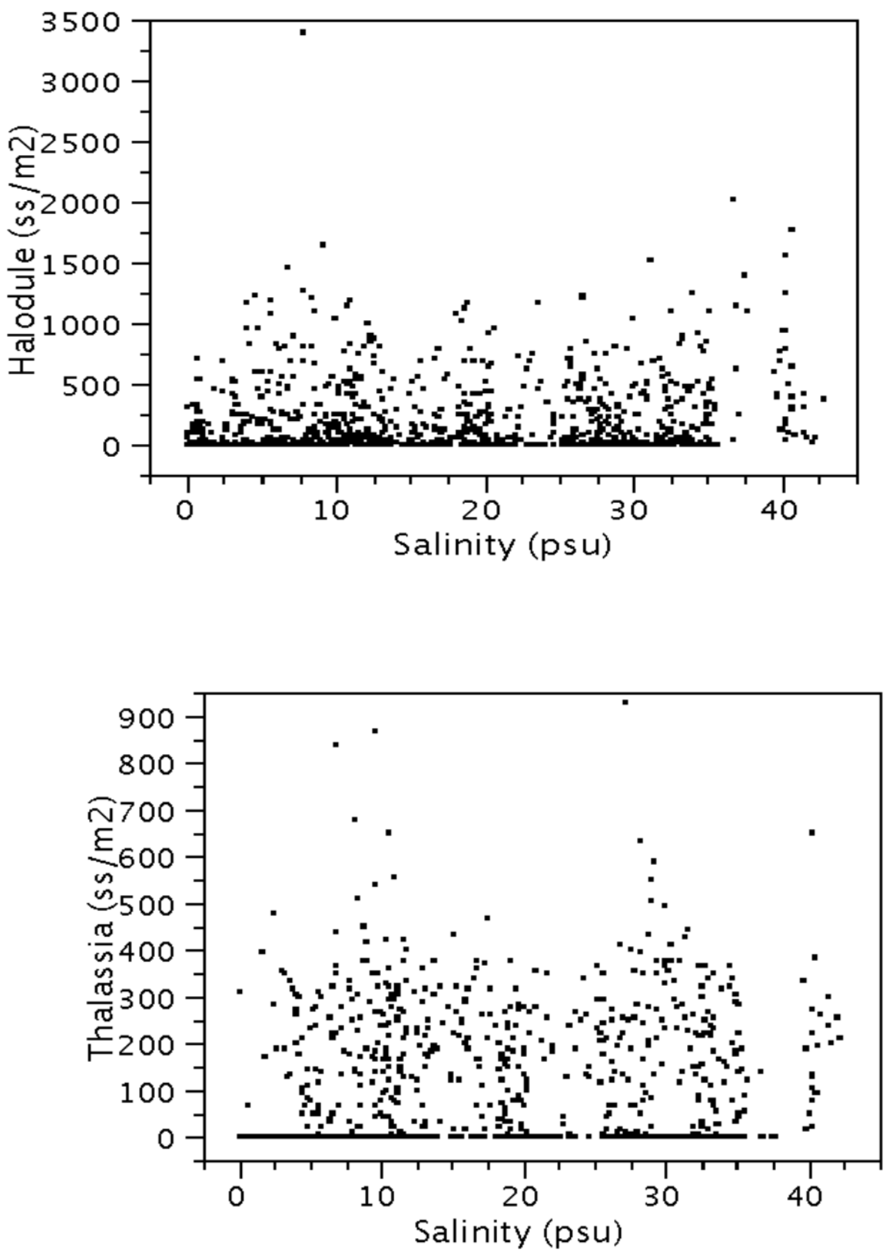


Figure 40. Density of *Halodule* and *Thalassia* Shoots in Relation to Salinity in Northeastern Florida Bay. Data collected by Miami-Dade Department of Environmental Resource Management (DERM) in Little Madeira Bay, Joe Bay and Long Sound from April 1999 to September 2004.

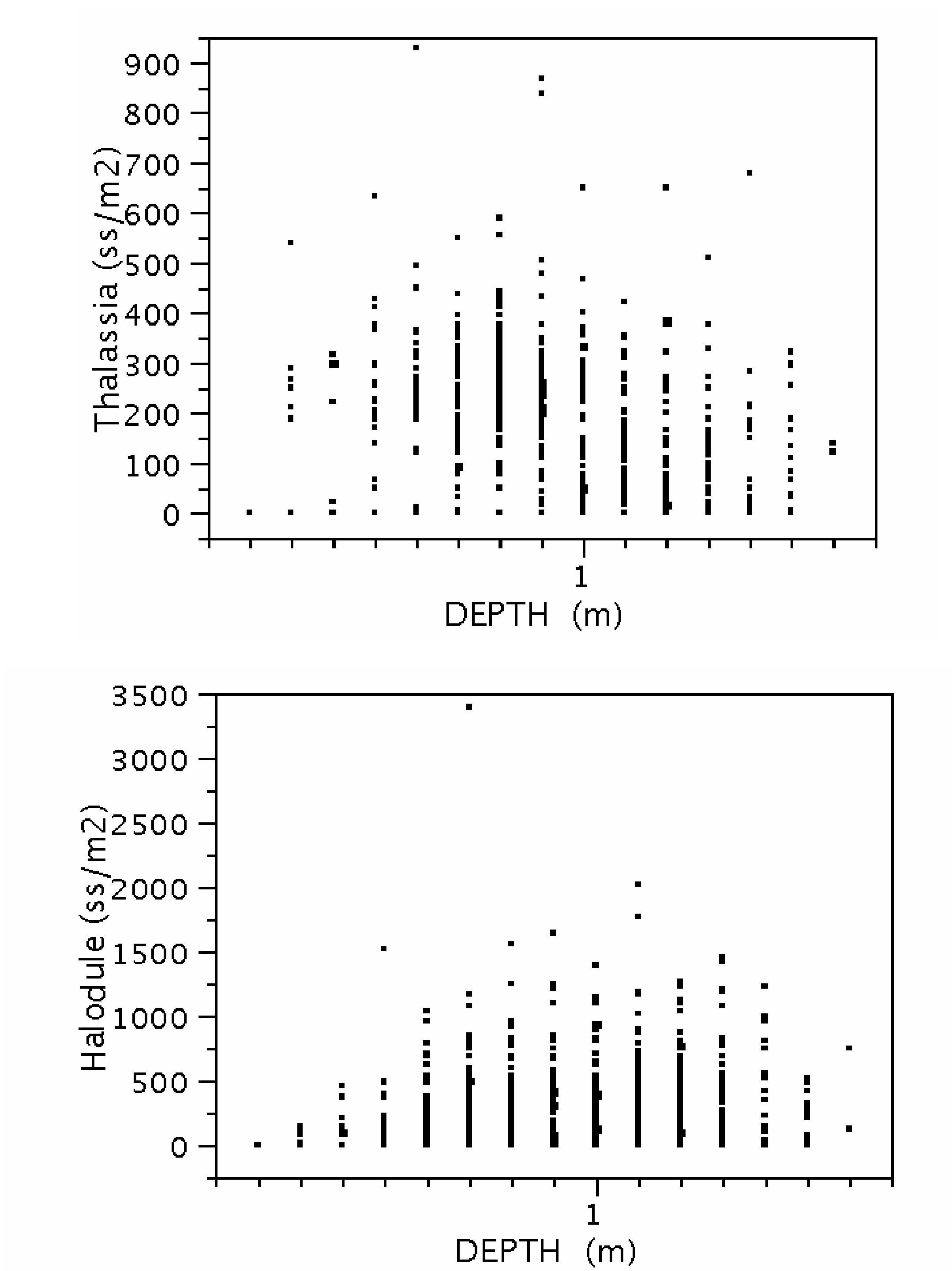


Figure 41. Density of *Thalassia* and *Halodule* shoots in relation to water depth in northeastern Florida Bay. Data were collected by Miami-Dade Department of Environmental Resource Management (DERM) in Little Madeira Bay, Joe Bay and Long Sound from April 1999 to September 2004.

Laboratory Analyses

Mesocosm studies were performed with *Thalassia testudinum* and *Halodule wrightii* plants from Florida Bay to determine their physiological tolerance to salinity and the optimal salinity range for the two species (Koch and Durako 2004). Results showed that in the short term, *Thalassia* survived and continued to produce shoot material at salinity as high as 50–60 psu. At 70 psu, plant standing stock biomass significantly declined. *Halodule* continued positive production of biomass up to 70 psu. However, in these experiments, measurements of osmolality and photosynthetic yield indicated that the energetic cost to the plant of maintaining an osmotic gradient, even at lower levels of hypersalinity, was significant and stressful to the plant. In the field, these species are rarely found at salinity as high as 60–70 psu, likely due to additional stress factors present in the environment and/or altered competitive capabilities.

These results indicate that high salinity alone is not sufficient to cause catastrophic losses of adult plants of *Thalassia, Halodule* or even *Ruppia*. As in the earlier described case with *Ruppia maritima*, moderately hypersaline conditions in controlled environments did not cause significant impacts on either *Thalassia* or *Halodule*, which were able to adjust internal solute concentrations osmotically to tolerate exposure to high salinity. Adult *Thalassia* and *Halodule* grown in sediments were tolerant of high salinity and maintained or even increased shoot numbers at salinity from 35 to 60 psu, when other physiochemical factors were held at optimal levels. In these experiments, plant standing stock began to decline significantly at 70 psu. Tissue osmolyte concentrations increased in all salinity treatments above 40 psu in both species, indicating plant stress and the energy expenditure needed to counteract the higher salinity outside the plant. Photosynthetic efficiency began to decrease at 60 psu in both species. The increase in osmolyte concentrations and decline in efficiency indexes indicate that the species were impaired in terms of energy balance and photosynthetic function. Shoot numbers were unaffected during the 60 day period that these plants were exposed to high salinity (Koch and Durako 2004). In a similar study with *Thalassia* seedlings, the young plants were found to be more sensitive than adult plants to high salinity and were unable to survive at levels above 50 psu (Koch and Durako 2004).

Although increased salinity alone is not sufficient to cause a catastrophic die-off, a combination of stress factors including salinity, higher temperature and higher sulfide can significantly decrease seagrass survival (Koch and Durako 2004). Leaf productivity rates and shoot counts of adult Florida Bay seagrass species did not change, or in some cases even increased, at salinity ranging from 35 through 60 psu (Koch and Durako 2004), but these same seagrass species were strongly impaired by moderate hypersalinity when an additional stress factor also was present. Mesocosm experiments by Koch and Durako (2004) tested the effects of combined salinity and temperature stressors on *Thalassia, Halodule* and *Ruppia*. With a small increase in temperature above average ambient Bay temperatures, salinity of just 40 psu resulted in a 15 percent lower photosynthetic efficiency of *Thalassia* as compared with the efficiency at 35 psu. At 50 psu, efficiency was only 50 percent of that at 35 psu. When temperature was slightly elevated, *Ruppia* showed a similar but less pronounced response, exhibiting declines of about 15 percent efficiency at salinity of 40 and 20 percent at 50 psu. *Halodule* was not significantly influenced by temperature increases at any level of salinity. An earlier study of combined stressors (salinity plus sulfide) by Koch and Erskine (2001) showed that exposure of hydroponic *Thalassia* plants to a 6 μM sulfide concentration and salinity of 56 psu for two weeks resulted in a 50 percent decline in leaf biomass and shoot abundance relative to plants exposed to a similar sulfide level at 35 psu. Thus, high salinity alone may not provide sufficient stress to cause catastrophic die-off, but a combination of stress factors, including hypersalinity, temperature and sulfide can significantly decrease seagrass survival (Koch and Durako 2004).

Determination of an appropriate salinity range for sustaining a mixed *Thalassia testudinum* and *Halodule wrightii* assemblage in Florida Bay is a challenging task. The relationship of plant vigor to salinity in a controlled laboratory environment must be interpreted cautiously when extrapolating to the dynamics of populations in the field. Researchers are currently initiating mesocosm experiments involving multiple species. Pending those results, computer models of the seagrass community are being used as a means to predict how elevated salinity will affect plant and community composition and survival in single and mixed species beds.

Ecological Modeling Analyses

A model developed for Florida Bay was used to examine responses of *Thalassia testudinum* and *Halodule wrightii* to multiple environmental stresses and to provide estimates of biomass under different freshwater flow conditions (Madden et al. 2003, Madden and McDonald 2006). The Florida Bay Seagrass Model is a set of separate spatially-averaged, mechanistic unit models calibrated to produce ecologic simulations of the seagrass community at different sites in different basins of Florida Bay. Response variables that are calculated include 1) species composition, 2) percentage cover and 3) biomass for each species. Important inputs to the model include salinity, inorganic nutrients, temperature, initial species composition, initial biomass, light and initial sediment sulfide concentrations. Other variables are internally derived, including concentrations of organic matter and interstitial hydrogen sulfide concentration in the sediments. The model runs with a three-hour time step using monthly mean estimated-salinity inputs from the FATHOM model for long simulation periods (33-year) and from averaged field salinity data for shorter (five-year) simulation runs. Salinity and temperature relationships are defined for each species on the basis of mesocosm studies described earlier (Koch and Durako 2004).

The dual-species model presented here incorporates the effects of interspecific competitive interactions between *Halodule* and *Thalassia.* The model is calibrated for two sites in the Taylor River's area of influence along the southern portion of the Everglades-Florida Bay Transition Zone transect (**Figure 23)** These sites are: Little Madeira Bay, near the mouth of Taylor River; and Eagle Key Basin, just south of the mouth of Little Madeira Bay. The baseline *Thalassia-Halodule* model uses averaged annual curves (interannual average for each Julian day) for the input variables from 1996–2001. The model produces stable populations of *Thalassia* and *Halodule* for both sites, and when calibrated with site-specific environmental data, the model simulates biomass for both target species agree well with field data for each site (**Figure 42**).

The model is used as a predictive tool, but care is taken in interpreting results because of the uncertainties in both the model itself and in the data used in the model. Model uncertainty has been examined (see Appendix I), and values of RMSE (root mean square error) for *Thalassia* biomass were 8.7 g-cm^{-2} in Little Madeira Bay and 3.1 g-cm^{-2} in Eagle Key Basin and for *Halodule* were 2.1 g-cm^{-2} in Little Madeira Bay and 1.1 g-cm^{-2} in Eagle Key Basin. Although some components are still in the parameterization process, the model represents the major processes and interactions in the seagrass community well. The results discussed in this study indicate that significant competitive interactions for nutrients and light occur among plants *in situ* and the outcome of this competition seems to be strongly influenced by salinity levels.

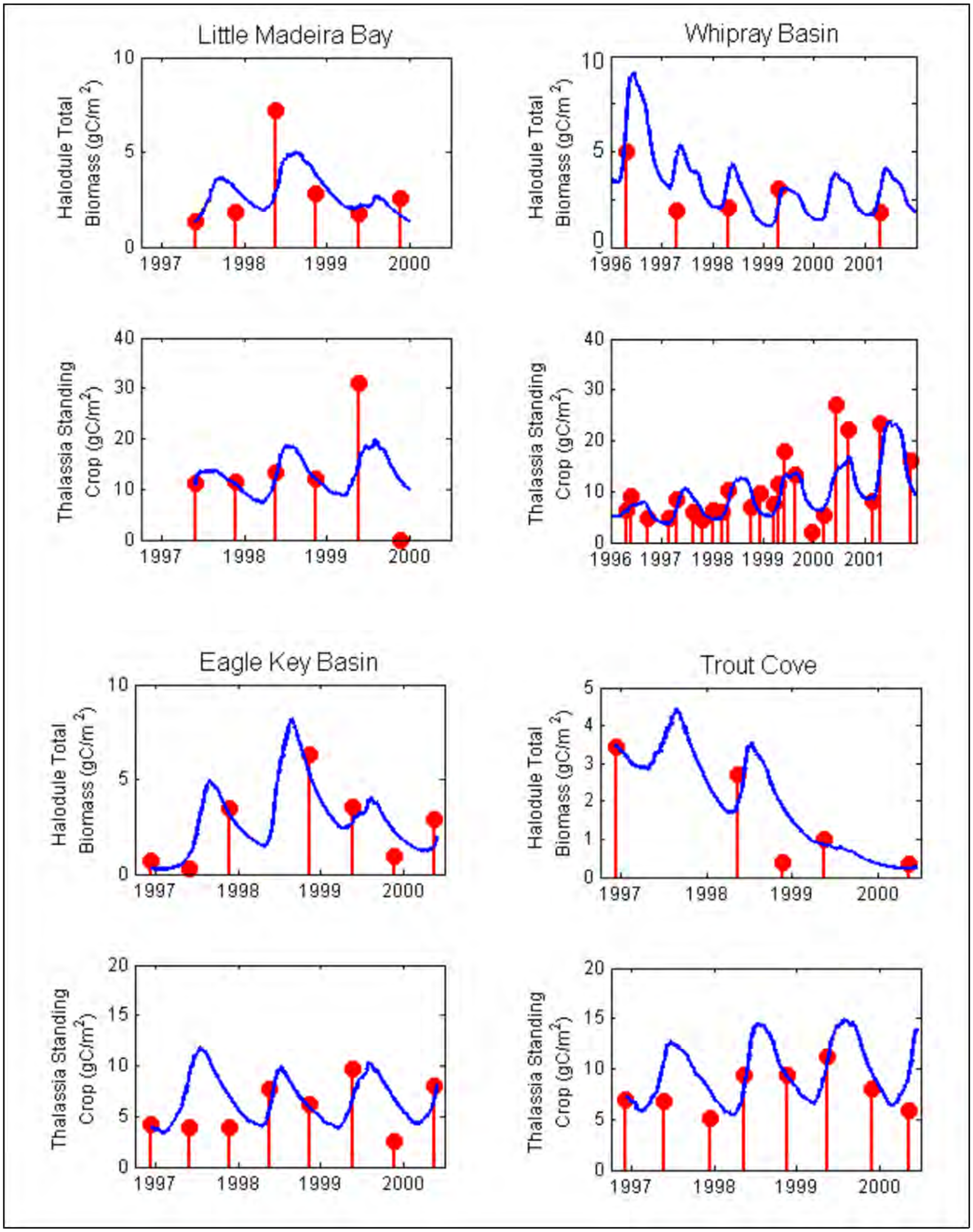


Figure 42. Calibration of SAV Biomass for a Dual Species Seagrass Model (*Halodule* and *Thalassia)* for Little Madeira Bay, Eagle Key Basin, Whipray Basin and Trout Cove. The latter two sites are not discussed in this MFL analysis. Model output [solid lines] for *Halodule* is total plant biomass, and for *Thalassia* is aboveground biomass, both in g-cm^{-2}; solid circles represent calibration data from field measurements).

Use of the Model to Investigate Salinity Scenarios

The simulation model was used to investigate the effects of salinity variation on seagrass community dynamics. Different salinity regimes, corresponding to a range of freshwater inflow rates, were systematically applied to the average five-year salinity baseline pattern and the model was run to predict changes in seagrass biomass and composition by species. Five-year simulations for the 1996–2001 period were run to analyze the effects of elevated salinity on SAV bed mortality and recovery at the Little Madeira Bay site. Baseline salinity inputs were derived from average values at the mouth of the Taylor River. For a sensitivity simulation presented in **Figure 43** the salinity level for each day was increased by 20 psu above baseline salinity, yielding a maximum salinity of about 50 psu and a minimum salinity of about 20 psu. This range approximately equals the levels observed near Little Madeira Bay during severe drought years (such as 1989 to 1990).

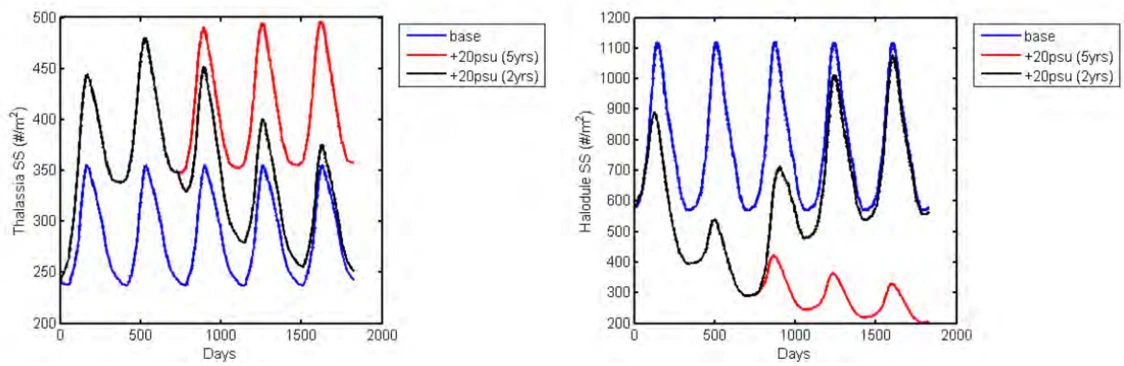


Figure 43. SAV model results from five-year simulations of elevated salinity in northeastern Florida Bay at the calibration location in Little Madeira Bay, along the Everglades-Florida Bay transition zone transect (see **Figure 23**). The figure shows *Thalassia* and *Halodule* short-shoot densities resulting from five-year simulations of the dual species model. Three treatments are shown; 1) a baseline salinity exposure, corresponding to average salinity in Little Madeira Bay repeated over five years; 2) an increase from the baseline by 20 psu for two years, followed by a return to baseline salinity for the next three years (black line); and 3) a five year period with salinity 20 psu above the baseline (black line through year two and red line thereafter). *Thalassia* responded favorably to elevated salinity, but *Halodule* rapidly declined and was impaired after two years that it did not immediately recover when salinity returned to normal. After a five year exposure to elevated salinity *Thalassia* remains elevated and *Halodule* essentially died off.

The salinity regime used in the model sensitivity analysis is similar to the intermediate salinity treatment in the mesocosm study by Koch (2003) and Koch and Durako (2004). Results from the model run showed that *Thalassia* had a strong positive response to increased salinity, and *Halodule* was impaired within two years and was eliminated within 5 years after increasing salinity by 20 psu (Madden and McDonald 2004). The response of *Halodule* modeled alone with elevated salinity was negligible (not shown); *Halodule* declined at higher salinity only in the presence of *Thalassia.*

The model was configured to allow a recovery from high salinity conditions. Salinity was reduced to baseline levels after two years in order to assess the SAV community's ability to recover to pre-stress levels. The early stages of the resulting five-year runs reflect the pattern just described for both species, with significantly lower *Halodule* biomass at higher salinity. *Thalassia* shows an increase of about 20 percent in biomass, which is maintained even after relaxation of the salinity stress after two years, reflecting a new equilibrium point for the population. In contrast, *Halodule* responded weakly when salinity was relaxed to the baseline level, and recovery was only about 50 percent in one year and 90 percent in two years. *Halodule* did not return completely to the pre-stress biomass level even after three years of “normal” salinity. Indications are that when *Halodule* is impaired in this way for periods > 1 year, recovery times may be long because of increased dominance of *Thalassia* and because of mortality of *Halodule* seeds and belowground material and the ensuing low recruitment. This result of the model analysis supports field observations. *Halodule* virtually disappeared from its common range during 1989–1994 following the *Thalassia* die-off event and then remained persistently low for several years, despite a return to lower salinity conditions.

Long-Term Historical Retrospective Model Analysis

Another analysis was performed by modeling a 33-year (1970-2002) retrospective simulation of SAV trends using the calibrated SAV model and salinity estimates generated as output from the FATHOM model historical reconstruction. FATHOM salinity estimates for Basin 14 (Little Madeira Bay) and Basin 15 (Eagle Key Basin) along the Everglades-Florida Bay Transition Zone transect were used for the two simulation runs. This analysis was conducted to evaluate the effects of historical droughts and other low flow and high salinity conditions on the SAV community response over long periods and during periods when almost no environmental data or data on the SAV community were collected. The analysis enables us to provide a best estimate of seagrass community response to historically high salinity conditions.

Results from these model runs showed clear responses of seagrasses to salinity **(Figure 44**), as *Thalassia* became the dominant species during periods of elevated salinity. During the three periods in the historical record when salinity remained above 40 psu for two or more consecutive years at the Little Madeira site, *Thalassia* growth was favored at the expense of *Halodule*. Immediately following extended periods of elevated salinity, increased freshwater flow from Taylor River resulted in lowered salinity. By the late 1990s *Thalassia* was nearly eliminated from the Little Madeira Bay site. In Eagle Key Basin, about 5 km from Taylor River mouth, salinity remained higher, favoring *Thalassia* and suppressing *Halodule* growth from 1970–2003. Briefly during the mid-1980s, and then persistently beginning in the mid-1990s, the onset of reduced salinity corresponded with increased *Halodule* biomass at Eagle Key and resulted in the development of a mixed *Thalassia-Halodule* assemblage.

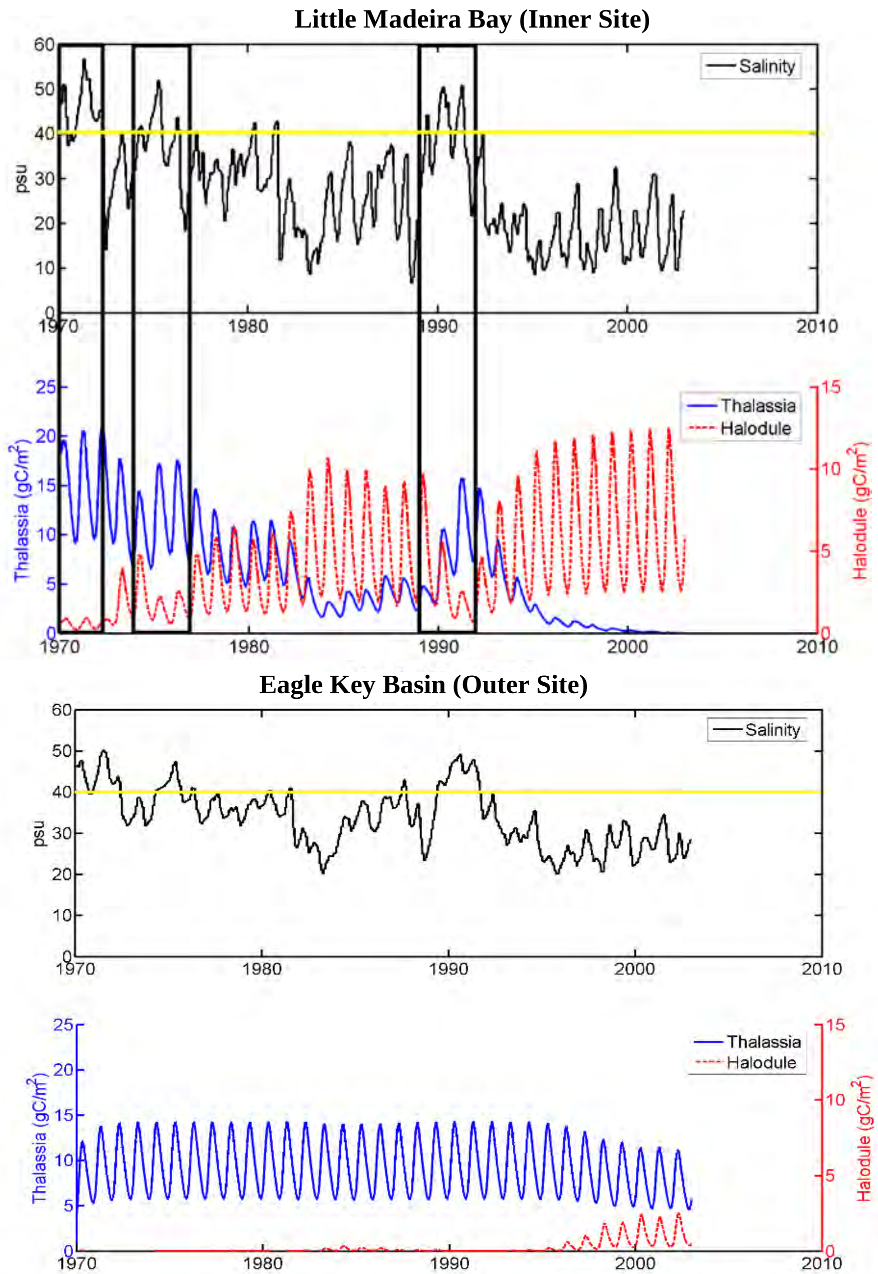


Figure 44. Seagrass Model Results from 1970–2002 Historic Reconstruction. The seagrass model was applied to [a] Little Madeira Bay [top panel] and [b] Eagle Key Basin [bottom panel] sites, located along the Everglades-Florida Bay Transition Zone transect (**Figure 23**). FATHOM predictions were used as input salinity; average monthly data were used for remaining environmental variables; the time series for salinity from the FATHOM model and biomass for *Thalassia* and *Halodule* are shown for the 33-year reconstructed historical period 1970–2002; three periods correspond to loss of *H. wrightii* at the inner site shown in the boxed area: [1] 1970–1971 drought, [2] mid-1970s and [3] 1989–1990 drought; in all cases, marine-to-hypersaline conditions prevail for >1 year; note development of monospecific *Thalassia* beds at the inner site in the early 1990s and decline in wetter years of the mid-1990s; at the outer site, *Thalassia* is the dominant seagrass from 1970 to the mid-1990s, when a mixed bed appears during the wetter period in the mid-1990s).

The modeling results reflect changes in species composition for the *Thalassia -Halodule* community that correspond to field observations along the Everglades-Florida Bay Transition Zone transect (**Figure 23**) in Little Madeira Bay and Eagle Key Basin. This result differs from what might have been expected based on the outcome of the previously described mesocosm experiments, which indicated that *Halodule* and *Thalassia* have similar levels of salinity tolerance. The decline in *Halodule* as a function of salinity occurred in the model when both species were competing for the same resources. When modeled independently, the decline in *Halodule* biomass did not occur.

Mesocosm studies demonstrated that elevated salinity alone cause internal physiological stress (but not necessarily lack of growth) in seagrass plants even in otherwise ideal conditions of light, nutrients and oxygen. Similarly, the dynamics of interspecies competition may be shifted by high salinity *in situ* and in the model. Such a shift could cause *Thalassia* to outcompete *Halodule* for nutrients but also for light and space at particular locations. In the field, sulfide-rich sediments and interspecies competition appear to provoke a decline in the vigor of both species at elevated salinity levels (Madden et al. 2003). The model prediction derives from the reduced ability of *Halodule* to compensate for hypersalinity in the face of such multiple environmental stresses, which in turn reduces its ability to compete successfully with *Thalassia* for limited resources.

These model results reflect dramatic shifts that were actually observed in Little Madeira Bay and Eagle Key in recent years. It is instructive to look also at the longer-term field data on biomass for both species in Little Madeira Bay, which were collected from 1997–2003, as shown in **Figure 45.** Unfortunately, recent data beyond 2001 were not available for similar analysis of Eagle Key Basin.

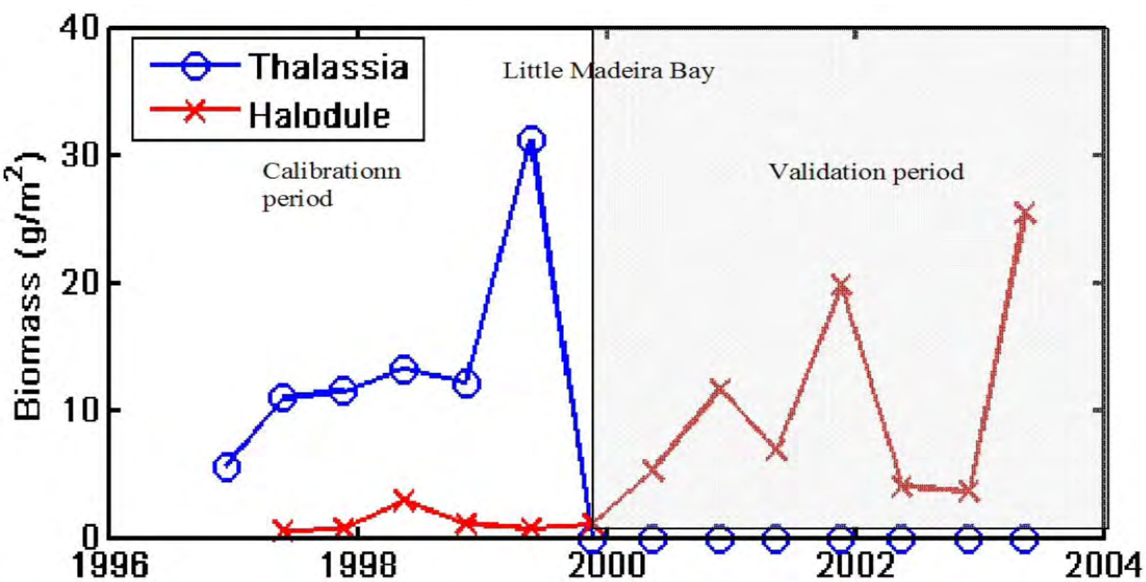


Figure 45. Measured Biomass of *Halodule* and *Thalassia* at the Little Madeira Site near the Mouth of Taylor River. The data include measurements used in the calibration of the seagrass model (1997–2001) and measurements in subsequent years (2001–2003), which can be used to validate the model. Compare this graph of observed data with model predictions shown at the top of **Figure 44.**

Though the 33-year model run did not incorporate these newer field data into its calibration dataset, the field response during the ensuing two years at Little Madeira Bay was consistent with model predictions. As flow increased in the late 1990s, *Thalassia* declined to zero and *Halodule* became the dominant species at the Little Madeira site. The species switch predicted for Little Madeira Bay toward the end of the 33-year model run (**Figure 44**) and the observation that such a switch actually occurred in the field after the model's calibration dataset time period, strengthens confidence in the model. The drop in biomass of *Thalassia* occurs earlier in the model than in the field and the population declines to zero over a period of years, whereas the drop in the field population was abrupt. Nonetheless, the model clearly responds to freshwater input (as predicted by the FATHOM model) and the disparity between data and model is likely a rate issue rather than a conceptual or structural issue in the model.

Output from the 33-year, dual-species, retrospective simulation was analyzed by regressing monthly SAV biomass outputs against monthly salinity estimate inputs. The result showed no discernible trend for *Thalassia* biomass as a function of salinity (data not shown), supporting the conclusion that *Thalassia* is very tolerant of high salinity. In contrast, in a similar regression analysis of *Halodule*'s response to salinity in the dual-species model, biomass declined with salinity above 30 psu along the Everglades-Florida Bay Transition Zone transect at both the Little Madeira Bay and Eagle Key Basin sites (**Figure 46**). The illustration shows salinity ranges (light blue) in which *Halodule* achieved maximum standing crop; this area corresponds to salinity below 30 psu. The green areas reflect salinity (above 30 psu) at which *Halodule* biomass was much less than the maximum. The yellow areas of the graph show where *Halodule* failed to achieve significant biomass. As noted in earlier sections, these salinity responses (and especially the finding of distinct salinity thresholds) are not a direct result of the model's algorithm for photosynthesis and respiration as a function of salinity alone but are instead a secondary result associated with changes in interspecies competition as a function of salinity—an emergent property of the model.

The replacement of *Thalassia* by *Halodule* as predicted by the model for Little Madeira Bay reflects this emergent property. Both species individually tolerate a wide range of salinity, but competitive factors indicate that each species can gain an advantage within different portions of this range. The finding of greater *Halodule* salinity sensitivity in Eagle Key Basin versus Little Madeira Bay (**Figure 46**) may reflect an interaction between salinity and nutrient availability, since sedimentary phosphorus concentrations are lower in Eagle Key Basin than in Little Madeira Bay. *Thalassia* may have an advantage in nutrient uptake from the phosphorus-poor sediments because it has a deep and expansive belowground biomass and greater capacity for internal nutrient storage.

SAV of Northeastern Florida Bay: Summary

The seagrass community of northeast Florida Bay tolerates high salinity for limited periods, but other concurrent factors must also be taken into account when making decisions about freshwater input to the estuary. Mesocosm experiments and modeling analyses show that when salinity increases above historical levels, shifts in seagrass physiology and in the population dynamics of seagrasses make the community less stable and diverse. When conditions shift too far, a major impact, such as seagrass die-off, can ensue, resulting in a cascade of ecosystem effects. Several layers of analysis may be required to make the connection between physiology of a particular species and overall community or ecosystem dynamics. Available information and analysis is sufficient to warrant caution in allowing salinity levels to rise above 40 psu in northeastern Florida Bay, particularly at certain times of the year. Based on the model output, *Halodule wrightii* appears to be especially vulnerable to high salinity conditions during the late dry season and summer when temperatures are elevated and water circulation is restricted.

Mesocosm experiments did not show a strong sensitivity of individual plants to high salinity in the short term (weeks to months), but model analysis of hindcast conditions and historical field data on long-term trends indicates that elevated salinity affected the *Thalassia-Halodule* community complex, including effects on species composition, succession, and ecological function. When combined with other "natural" stresses such as nutrient limitation and sulfide toxicity, high salinity were shown by mesocosm studies and model projections to compromise seagrass community function by reducing *Halodule* cover and increasing *Thalassia*. In particular, when salinity in the model was persistently above 40 psu, species dominance in the *Thalassia-Halodule* assemblage shifted to favor *Thalassia* at the expense of *Halodule* and to drive the system toward an unstable monoculture.

Additional information must be gathered before making definitive determinations, but it is likely that salinity levels persistently above 40 psu are detrimental to the Florida Bay ecosystem.

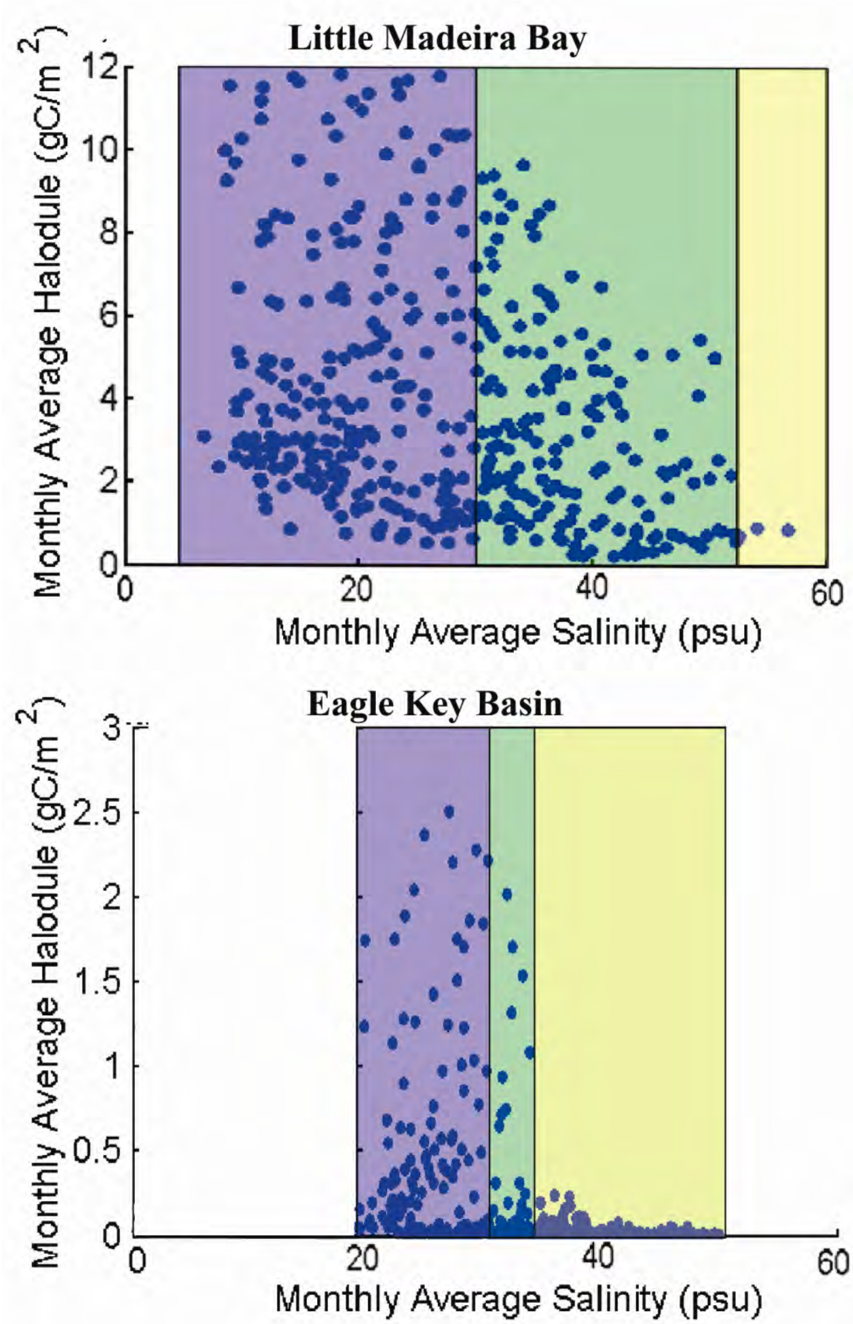


Figure 46. Seagrass Model Simulation of *Halodule* Biomass in Relation to Salinity from a 33-Year Historical Reconstruction. FATHOM salinity were used as input for two sites along the Everglades-Florida Bay Transition Zone transect (**Figure 23**). This analysis shows a strong decline in biomass at both inner Little Madeira Bay (top panel) and Eagle Key Basin (bottom panel) sites with increasing salinity. The blue area shows salinity at which *Halodule* achieves maximum standing crop (below 30 psu for both sites). The green area corresponds to salinity at which *Halodule* standing crop is declining. The yellow area shows where *Halodule* fails to achieve biomass values significantly above zero and is considered severely or lethally impaired). Note difference in vertical scales of the two plots, which reflect differences in overall productivity between these two regions.

Analysis of Higher-Trophic-Level Species of Northeastern Florida Bay

Statistical models were built to examine how Florida Bay fish and invertebrate species respond to variables of habitat and salinity. The General Additive Model (GAM) approach used for this work is a relatively recent development in statistical modeling that has been used in a number of ecologic and fishery population studies (Swartzman et al. 1992, Augustin et al. 1998, Fewster et al. 2000, Clarke et al. 2003, Ciannelli et al. 2004). Similar to the more common technique of multiple linear regression, GAMs relate the dependent variable to possibly important independent variables (covariates). Covariates in the GAM approach are assumed to affect the dependent variable through additive and independent unspecified (not necessarily linear) functions, thereby allowing changes in abundance to be related to covariates without restricting the functional form of the relationship (Hastie and Tibshirani 1990).

GAMs were built that take into account spatial and temporal variability in Florida Bay fisheries datasets from multiple studies spanning a sampling period of nearly three decades (mid-1970s through 2001). Models were developed for seventeen common Florida Bay forage species and three predator species (two that were represented in the database as juveniles). Faunal samples were collected with three types of gear: throw traps, seines and trawls. Sampling gear bias was considered by developing separate throw-trap models for some species and combined trawl and seine models for other species. Continuous independent variables in these models included salinity, depth, water temperature and SAV density or standing crop for each common SAV species -- *Thalassia testudinum, Halodule wrightii* and *Syringodium filiforme*. Categorical variables included habitat type, Julian day and sample region (as aggregations of FATHOM basins).

Each of the modeled species is mobile and was collected in samples from all regions of Florida Bay, although abundance per species varied regionally (which is why region was added as a variable). For each species, data from all samples (Bay-wide) were used in model development. Additional model development details may be found in Johnson et al. (2005). Simplified visual examples of bivariate relationships between salinity (X-axis) and log-transformed density (Y-axis), holding all other variables constant, are shown in **Figure 47**.

These plots are simplified depictions of conditions actually experienced by the species in the field and represented in the multivariate models. They provide a useful summary of relationships among environmental variables and predictions for species density and trends. Because GAMs were used for this work, relationships between fish/invertebrate density and a variable were often complex. The mathematical structure of GAMs allows for univariate sensitivity analyses (for instance, as illustrated in **Figure 47** for salinity) holding other variables constant. As other variables (those not depicted on these plots) change in value, the slopes of the bivariate relationships for salinity will remain the same, while the intercept may change.

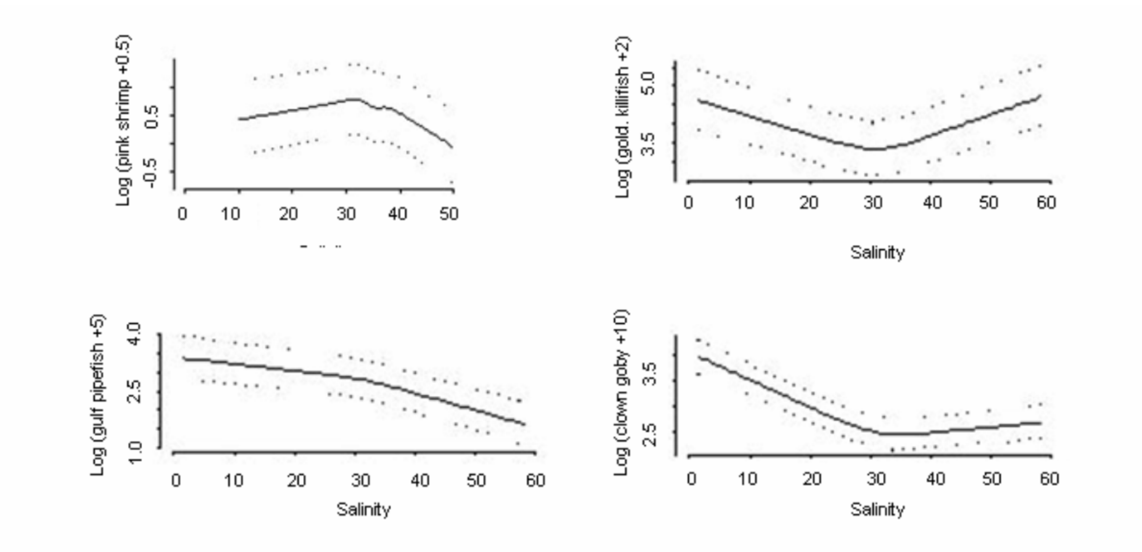


Figure 47. Statistical Model of Higher-Trophic-Level Species' Biomass as a Function of Salinity in Florida Bay. Graphs are examples of bivariate plots between log-transformed species' density and salinity, holding all other variables constant, with 95 percent confidence intervals (dotted lines).

Similar bivariate plots were interpreted to obtain the results presented in **Figure 48** for covariates salinity and density of *Thalassia, Halodule* and *Syringodium*. Salinity and at least one SAV species were significant variables in the GAM models for almost all taxa. Faunal density varied in a more complex manner as a function of salinity and *Thalassia* density than as a function of *Halodule* and *Syringodium* density. For the latter two SAV species, faunal density almost uniformly increased with increasing SAV density. For *Thalassia*, faunal density commonly increased with increasing plant density only when this SAV was sparse or moderate. Trends with salinity varied widely among species, but for most species, shifts in density occurred near marine salinity (30–35 psu).

A separate GAM analysis, using output from the dynamic Florida Bay Seagrass Model (described earlier), was performed to assess the interactive effects of salinity and SAV in northern Little Madeira Bay (near the mouth of Taylor River) (see **Figure 23**). A baseline salinity scenario was first developed by calculating average (by Julian day) salinity and temperature conditions from field data for this area. The seagrass model was then run for a five-year simulation period (as described in the SAV salinity scenario subsection, as for **Figure 43.** Model runs were repeated, using the average daily temperature data and different salinity values that were adjusted to represent increases in salinity relative to the average baseline values (by 5, 10, 15, and 20 psu). After SAV biomass was estimated by the Seagrass Model, these output data were converted to Braun-Blanquet Cover and Abundance (BBCA) density values (for each species) and input as monthly averages into the GAM trawl/seine models for each fish/invertebrate species. For each salinity scenario, associated inputs of salinity and temperature (also as monthly averages) that were used as input into the SAV model were also used for the GAMs. *Syringodium* cover was input to the GAMs as zero because this species is not found in the basin used for this analysis. Examples of inputs to the GAMs are shown in **Figure 49**.

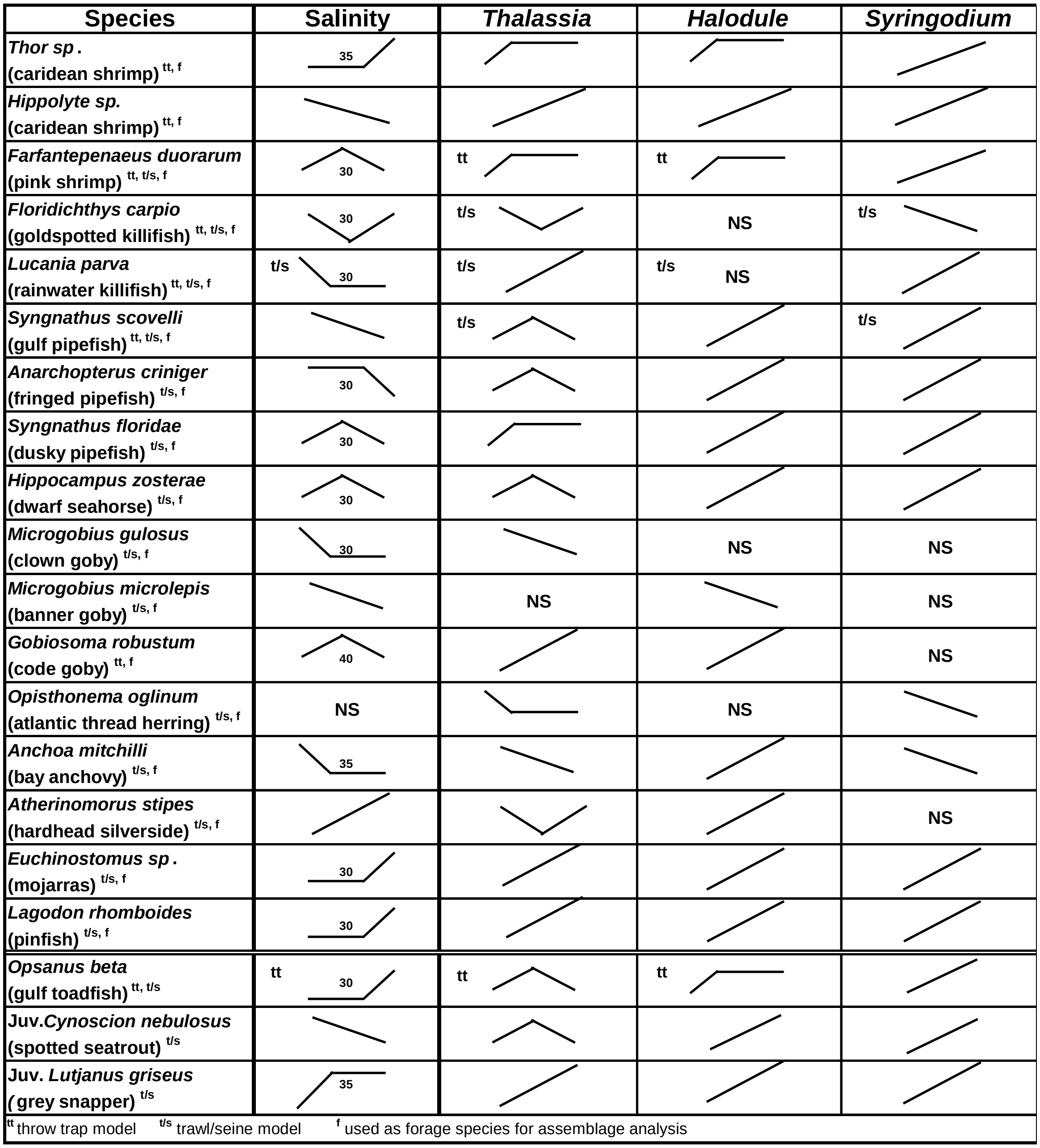


Figure 48. Summary of Results from Statistical Models for Twenty Florida Bay Fish and Invertebrate Species. The line plot within each cell indicates the generalized trend of species density as a function of the magnitude of a covariate, salinity (first column) or SAV density (by SAV species); "NS" designates variables that were not significant to a respective species model. Fourteen of these species (fish species indicated by "f" superscript) were selected as typical forage species for further impact assessment (see text).

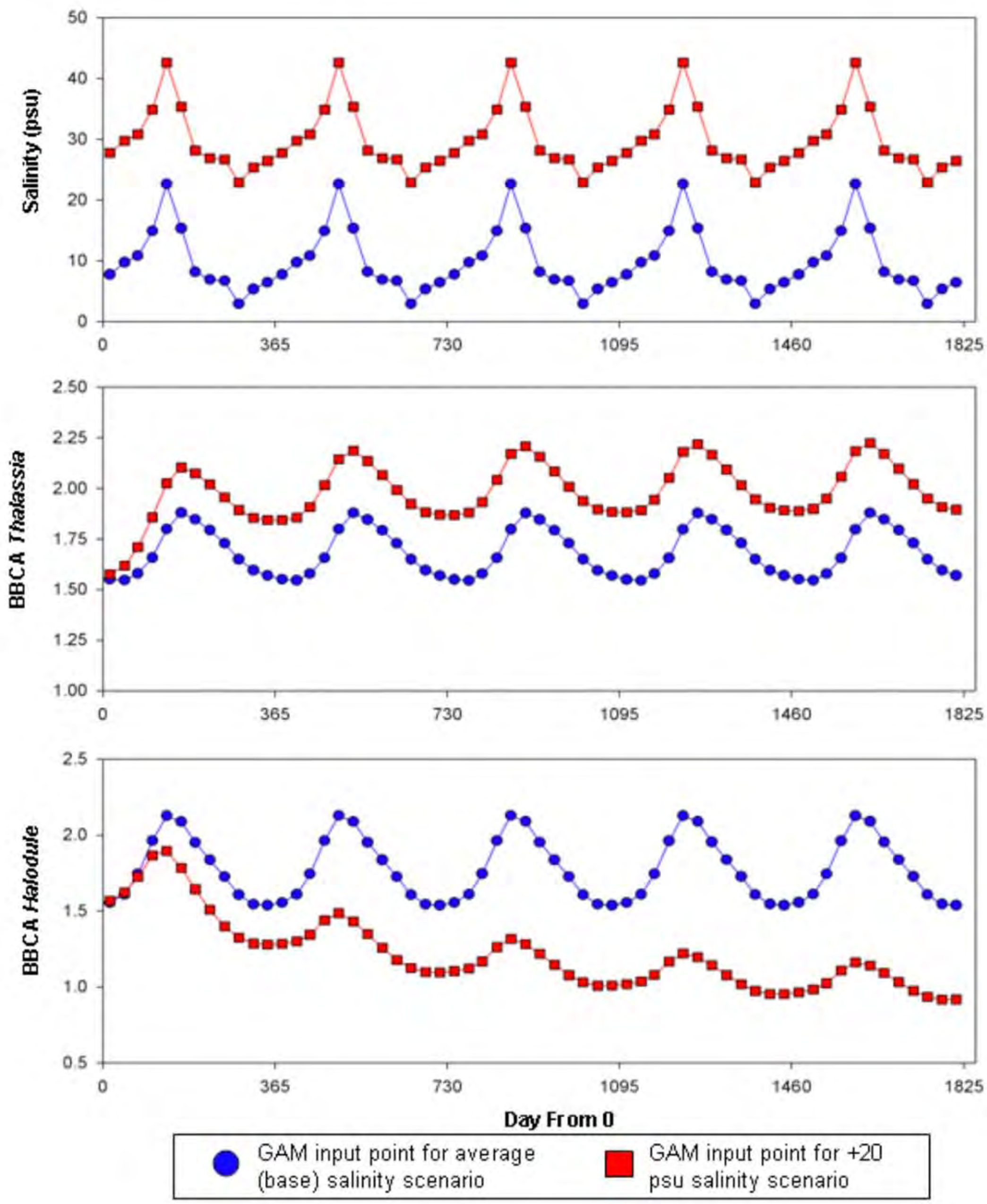


Figure 49. Salinity and SAV Habitat Inputs to the Higher-Trophic-Level Statistical Model, to Test Direct and Indirect Effects of Salinity Change on Animal Species. Plots show monthly salinity and seagrass cover (Braun-Blanquet Cover Abundance, BBCA) input data to GAMs, used to test salinity sensitivity of the fish models; above are time series results for two (of the five) salinity scenarios, run over five years through the Florida Bay Seagrass Model for the Inner Little Madeira Bay basin. These inputs to the GAMs were monthly averages of the Seagrass Model's daily input (salinity and temperature) and output (biomass of each SAV species, converted to a BBCA value [0–5 scale]).

The forage fish GAMs were used to make predictions for each month of the 5-year SAV model simulation. Results from the scenarios were examined for each fish/invertebrate species and were aggregated to assess effects on a forage assemblage composed of the 14 species identified in **Figure 48**. These assemblage results are shown in **Figure 50** for the average (base) salinity and 20 psu boosted salinity scenarios across the simulation period. The lower panel of **Figure 50** also shows predicted forage fish densities for the 20 psu boosted scenario as a proportion of the predicted densities for the base salinity scenario. While these results are presented for ease of interpretation as a time-series, it is important to note that the GAMs are independent of time and represent only static ("snapshot") results. Thus, the results should be viewed as conservative: these models do not reflect dynamic effects of predator/prey interactions or competition, population recruitment or other life history traits over time. This is in contrast to the SAV model that is capable of incorporating dynamic feedbacks into its results as time series outputs.

One noteworthy trend in the results from **Figure 50** is a consistent depression in predicted fish abundance in the higher salinity scenario versus the base case salinity. Though there is some month-to-month variability, the average decline in predicted forage fish density caused solely by the 20 psu increased salinity was approximately 15 percent. This trend in assemblage-level results was driven in large part by a subset of dominant species that declined based on salinity alone (e.g., bay anchovy and the 2 killifish species). By the end of the 5-year simulation period, the proportion of fish predicted to occur in the high salinity scenario dropped to (on average) just below 70 percent of that predicted for the base salinity condition. Because the annual salinity and temperature curves were repeated across the simulation period, this additional decline (of over 15%) can only be explained as a result of a change to the SAV inputs, specifically the drop in *Halodule* over time. As shown in **Figure 49**, there were several forage species that were predicted to decline as density of this SAV species dropped. One dominant member of the forage assemblage, *Euchinostomus* sp. (mojarras), was more sensitive to declining *Halodule* density than to the higher salinity concentrations in the raised salinity scenarios.

The importance of SAV habitat to the forage base assemblage is also evident in **Figure 51** in which the predicted forage fish densities for *all* salinity scenarios (and corresponding Seagrass Model outputs) are plotted versus both salinity and *Halodule* inputs for the month of April (for all years of the simulation period). In this plot predicted fish density drops in conjunction with both increasing salinity concentrations and decreasing density of *Halodule*, validating the importance of predicting the effects of these habitat conditions in concert. The results suggest that salinity effects on fauna occur not only directly via physiological stress on the fauna but also via habitat modification. This coordinated modeling exercise demonstrated 1) the importance of salinity and habitat as interactive factors that influence Florida Bay's higher trophic level species and 2) the validity of using SAV habitat as an ecosystem indicator for MFL development.

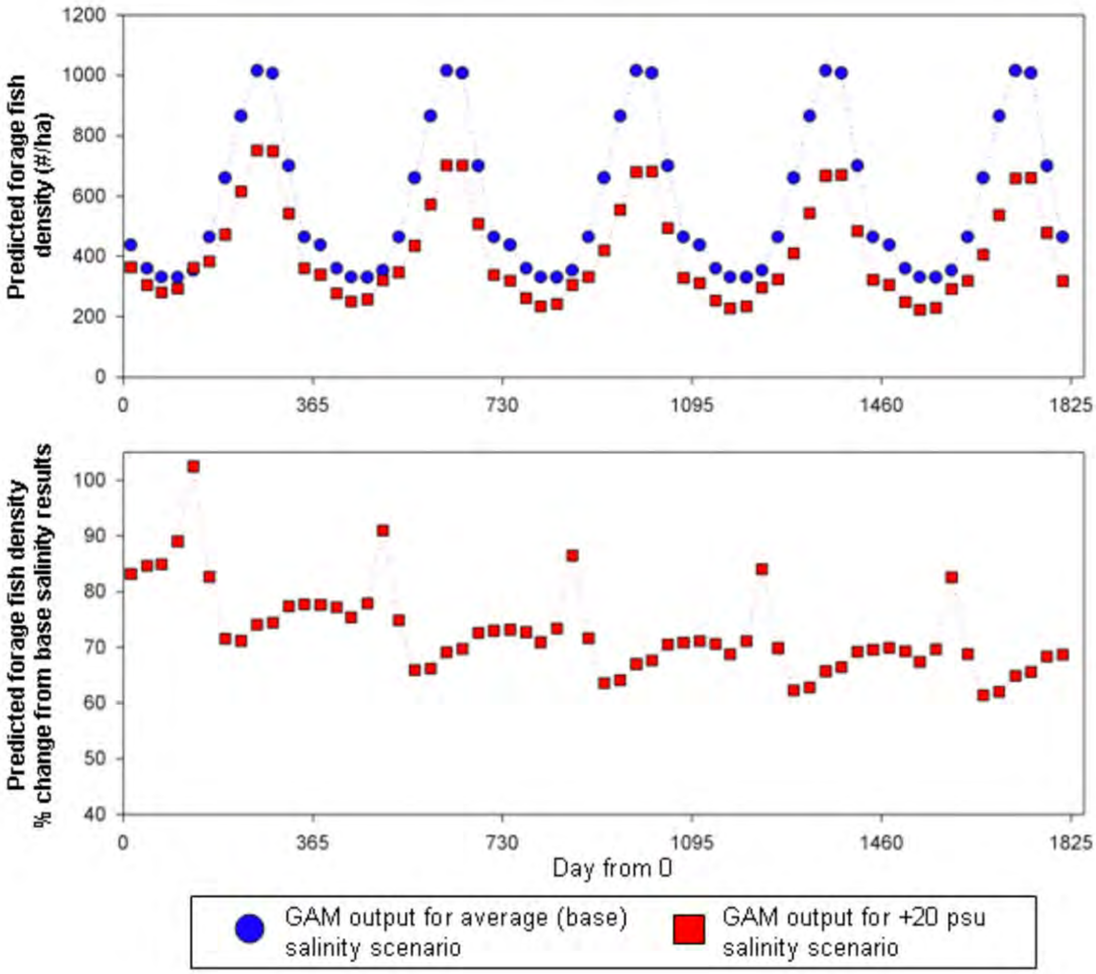


Figure 50. Results from Higher-Trophic-Level Statistical Models of an Assemblage of Fourteen Species, Showing Direct and Indirect (via SAV Habitat Change) Salinity Effects Over 5-Year Simulation Period. Results are estimated by GAM statistical models (trawl gear type only) for two (of the five) salinity scenarios run for the Inner Little Madeira Bay basin. Results are displayed as time series output for ease of interpretation with input datasets (**Figure 49**), though the GAMs themselves are static models that do not incorporate results into subsequent simulations over time. The top panel shows predicted fish densities (as a summation of prediction densities for the 14 modeled forage species) for both base salinity and 20 psu boosted salinity scenarios. The bottom panel displays the results for the 20 psu boosted salinity scenario as a proportion of the results for the base salinity scenario, and specifically highlights the effect of declining Halodule density over the simulation period in which the annual salinity curves were repeated.

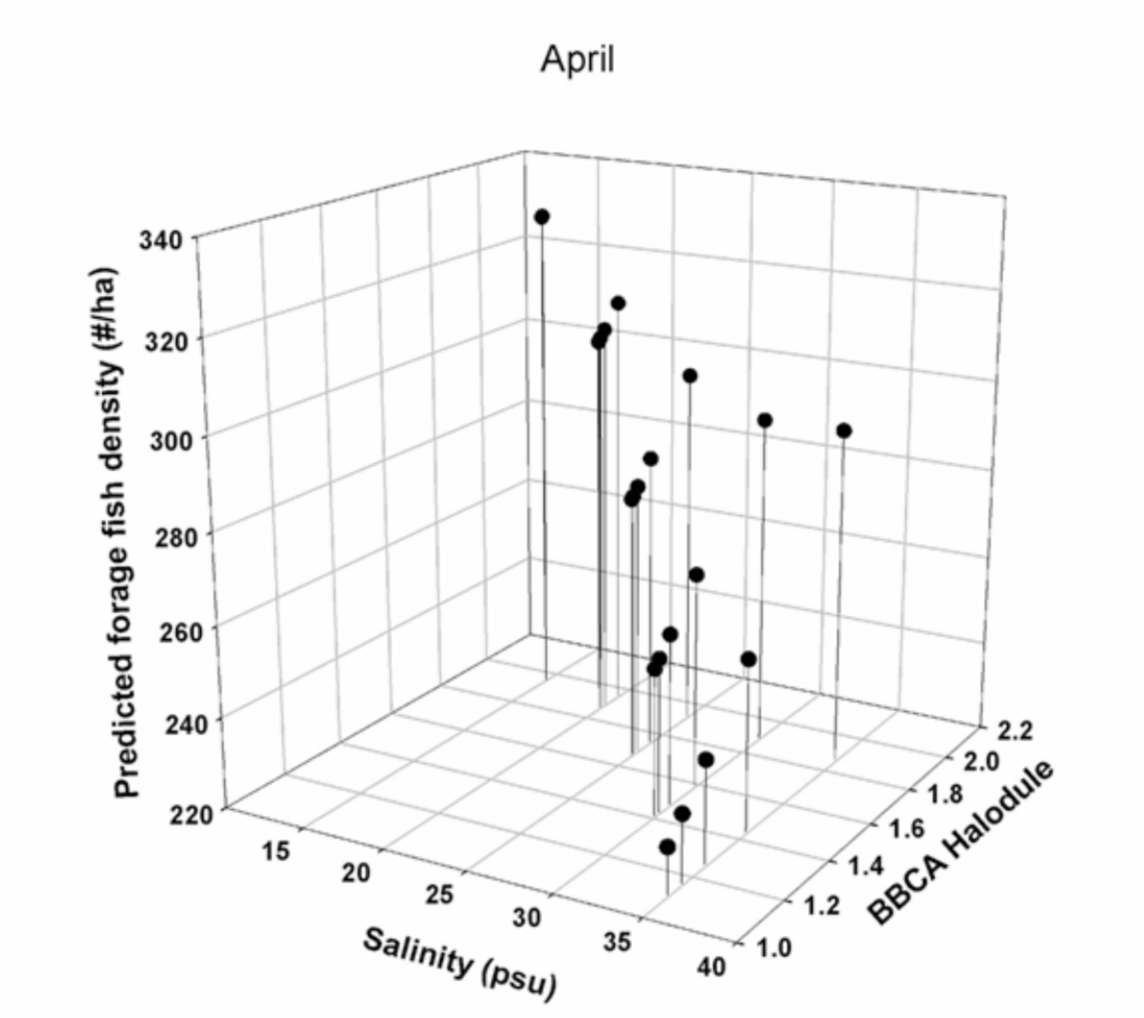


Figure 51. Results from Higher-Trophic-Level Statistical Models of an Assemblage of Fourteen Species, Showing Concurrent Effects of Salinity and SAV Habitat Change for All Salinity Scenarios. Results are estimated by GAM statistical models (trawl gear type only) for the Inner Little Madeira Bay basin for the month of April. For each salinity concentration, any change in BBCA for *Halodule* represents a change over the simulation period (note that for each scenario, salinity was held constant amongst years for each month). Changes in *Halodule* density over time had a compound effect with salinity on the predicted fish density.

CHAPTER 5: APPLICATION TO DEVELOPMENT OF A FLORIDA BAY MFL

SUMMARY OF TECHNICAL RELATIONSHIPS ANALYSES

Summary of Hydrologic Analyses

As part of the process to determine relationships between the amount of managed freshwater inflow and impacts to resources in Florida Bay, two models were used to predict salinity at various locations in Florida Bay:

- An updated FATHOM model was used to estimate salinity for each of 41 basins within Florida Bay for the historical period from 1970 to 2002.
- An existing multivariate linear regression (MLR) model was used to develop a time series of salinity conditions at the Taylor River station for this same time period.

FATHOM Model

The FATHOM model (Flux-Accounting Tidal Hydrology Ocean Model) was refined by including an updated bathymetry dataset, inflows, hydrologic data and time-varying salinity boundary conditions along the western boundary with the Gulf of Mexico (ECT, Inc. 2005). The result was considered a reconstruction that represents an approximation of the historical water budget. The model was calibrated with data collected during the 1991–2002 period. Model fidelity and predictions for this period varied somewhat by basin, but overall the FATHOM model explained about 81 percent of the observed monthly salinity variability throughout the 41 basins. Along the representative gradient, the FATHOM model explained 76 percent of the monthly salinity variability in Little Madeira Basin and 77 percent in Eagle Key Basin, sites located along the Everglades-Florida Bay Transition Zone transect.

The ability of the model to predict salinity under managed flow conditions was also assessed. Annual maximum salinity in basins located in the northeast and eastern interior region of Florida Bay were significantly correlated to year-to-year changes in inflow. The total average annual inflow to northeast Florida Bay shows an increasing trend over the 31-year period 1970 to 2000, but water budgets and flows into northeast Florida Bay prior to 1980 were distinctly different from those after 1980. The relative amount of surface water discharged into the Everglades–Florida Bay transition zone for a given rainfall amount after 1981 was about four times higher than the amount discharged during the period from 1970 to 1981. The difference is attributed primarily to changes in water management activities.

Two representative drought years, near the 10 percent probability level, occurred during the 31-year simulation period: 1971 and 1990. To account for apparent changes in water management practices, normal and dry years were defined in both the pre-1980 and post-1980 periods. This analysis indicated that even though the 1975 water year (Nov. 1, 1974 – Oct 31, 1975) had precipitation near the long-term average, the annual inflow to the Everglades–Florida Bay transition zone was comparable to the 1989–1990 drought period, due to water management practices.

Multivariate Linear Regression (MLR) Model

The second (MLR) model was applied to the Taylor River station, located at the upstream area of Everglades–Florida Bay transition zone for the historical period from 1970 to 2002. This model uses observed water level data from key gauges within Everglades National Park to predict salinity at the Taylor River monitoring site. The MLR model was used for this area because the FATHOM model does not extend to the upper reaches of Taylor River. The model was calibrated against field measurements collected during the 1988–2000 period and was shown to provide reasonable salinity estimates. The efficiency of the MLR model (a measure of the percentage of variance explained by the model variability) for monthly estimates was 84 percent. The largest errors tend to occur at the onset of the wet season and during extended periods of low flow.

Summary of Ecological Analyses

Submersed aquatic vegetation (SAV) habitat of the Everglades–Florida Bay transition zone along the coastline is sensitive to salinity, with loss of all major species occurring at levels above 30 psu. *Ruppia maritima*, the dominant vascular SAV of the transition zone, is the most salinity tolerant of this assemblage. The loss of this species near 30 psu is related not only to mortality of seedlings and of adult plants but also to inhibition of seed germination and of reproductive success above this salinity level. *Ruppia maritima* is proposed as an indicator species for the status of the transition zone-Florida Bay ecosystem.

SAV habitat in open water areas of northeastern Florida Bay is dominated by two species: *Halodule wrightii* and *Thalassia testudinum*. These species are more salinity tolerant than *Ruppia* and under optimal laboratory conditions can tolerate extremely high salinity levels (near 60 psu). Empirical field data do not show clear salinity trends, but these data are limited to low and moderate salinity conditions and insufficient to assess effects of hypersalinity. A dynamic simulation model of *Halodule* and *Thalassia* indicates that strong effects of salinity are likely to occur in the field because field conditions are not optimal. In particular, the effects of salinity are probably the indirect result of effects on competition between *Thalassia* and *Halodule* (especially for nutrients and light). Results based on field data and modeling suggest that under hypersaline conditions (above 40 psu), *Thalassia* becomes dominant, while under mesohaline conditions (less than 18 psu), *Halodule* is predicted to become dominant.

The quantitative and qualitative composition of the SAV community appears to have an impact on many fish and invertebrate species of Florida Bay. A statistical analysis of a multidecadal dataset from Florida Bay demonstrated that salinity has a significant (though widely varying) effect on these fauna and also that almost all fauna benefit from increased *Halodule* cover. Analyses indicate that in Florida Bay increasing the salinity level from mesohaline toward marine and hypersaline conditions tends to reduce the overall abundance of the forage base (small animals that are food for larger fish, particularly for sport fish) because of direct salinity effects on these organisms and because of loss of SAV habitat. Maintaining an estuarine condition (salinity commonly less than marine levels) will thus be protective of both habitat and faunal resources.

IDENTIFICATION OF FRESHWATER INFLOW-RESOURCE IMPACT RELATIONSHIPS

Key Findings

Based on analyses of hydrologic-ecologic relationships and results presented in Chapter 4, the following are key findings relevant to the development of the Florida Bay MFL.

- By analyzing salinity and resources along the Everglades-Florida Bay Transition Zone transect, conditions and impacts in Taylor River, downstream coastal embayments and northeastern Florida Bay can be examined concurrently.
- Freshwater discharges from the regional water management system have direct effects on salinity conditions and the ecology of the transition zone, coastal embayments of northeastern Florida Bay, and northeastern Florida Bay proper.
- The availability of submersed aquatic vegetation (SAV) and macroalgal habitat within the Taylor River gradient is an indicator of the health of the entire transition zone and of the adjacent northeastern Florida Bay ecosystem.
- Resources and functions of the transition zone and northeastern Florida Bay can be protected from negative impacts by taking appropriate actions to prevent multi-year recurrences of high salinity levels that jeopardize SAV habitat in the transition zone. For the Taylor River site, significant adverse changes occur in the SAV community when monthly average salinity exceed 30 psu.
- Field and laboratory studies indicate that when monthly average salinity exceeds 30 psu at the Taylor River site there is a loss of *Ruppia maritima* cover and the SAV community in this region. Recovery to pre-existing conditions would be expected to take a year or more.
- Re-occurrence of such conditions (monthly average salinity exceeding 30 psu) at the Taylor River site during successive years prevents the successful recovery of *Ruppia maritima* cover and the SAV community in this region and results in a sustained multi-year impacts to the resource. Greater duration and frequency of these adverse salinity conditions tend to exert correspondingly greater negative impact on the survival of the SAV community and associated organisms, as well as on productivity and water quality in the Everglades–Florida Bay transition zone, while allowing insufficient time for recovery to occur.
- Such salinity conditions also affect adjacent downstream basins in northeastern Florida Bay. During periods when monthly average salinity in the transition zone are above 30 psu, salinity in northeastern Florida Bay generally exceed 40 psu and may be considerably higher. Field and modeling studies indicate that extended periods of salinity above 40 psu in this region result in decreased *Halodule wrightii* (shoal grass) cover and adverse effects on upper-trophic-level organisms that utilize this habitat.
- Decreases in SAV diversity would be expected to occur under conditions of sustained hypersalinity, and decreases in Florida Bay fauna would be a likely consequence.
- Maintenance of monthly average salinity concentrations below 30 psu at the Taylor River Site should prevent major impacts from occurring to *Ruppia* and associated SAV and macroalgal species in the transition zone and should concurrently sustain conditions in coastal embayments and northeastern Florida Bay to prevent the sustained degradation and loss of SAV habitat and other associated living resources. Corresponding salinity conditions in these downstream estuarine areas are mesohaline (5–18 psu) conditions in the wet season and polyhaline-euhaline (18–40 psu) conditions in the dry season.

Historical Occurrences of Resource Impacts

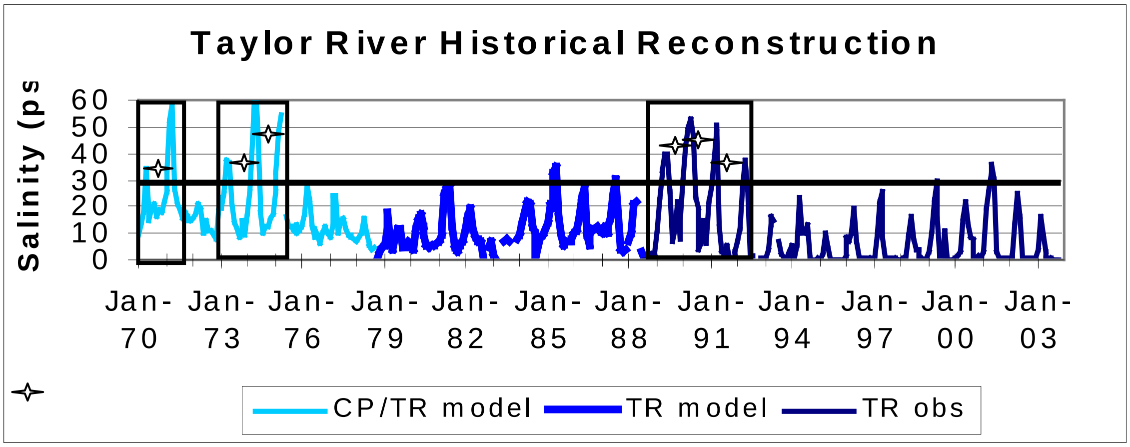
The present chapter examines the link between inflow and salinity during a reconstructed historical period from 1970–2002, and it provides a comparison of 1) the Taylor River estimates from the MLR model and 2) Florida Bay (FATHOM) estimates from the FATHOM model, highlighting the periods in which resource impacts as defined in the preceding section have occurred.

Transition Zone Modeling Results

Historic salinity conditions were reconstructed in the upper transition zone for the period, 1970-2002, using a combination of field measurements, which have been continuous at Taylor River site since October 1988, and estimates from the Taylor River MLR salinity model for 1970–1988 (**Figure 52**). The Taylor River site exhibits variable salinity and becomes hypersaline during the drought years that were identified in the water budget (see **Figure 52** [below] and **Figure 27** in Chapter 4). Analysis of the 33-year historical reconstruction of salinity for the Taylor River site indicated that the salinity threshold that impacts to SAV resources (monthly average salinity above 30 ppt) was exceeded during the 1970-2002 period as follows:

- Monthly average salinity exceeded 30 ppt during 12 of the 31 years
- Monthly average salinity exceeded 30 ppt during two successive years during 1970-71
- Monthly average salinity exceeded 30 ppt for three-years in succession from 1971-1975
- Monthly average salinity exceeded 30 ppt during four successive years from 1989-1992.

The analysis indicates that rainfall conditions were somewhat lower than average during the 1970's and somewhat higher than average during the 1990's. Major regional droughts occurred during the periods from 1971-72, 1974-75 and 1989-92, although 1974 and 1975 were not especially dry years in the southern Everglades and Florida Bay. There have been significant changes in water delivery facilities and practices during this reconstruction period. Current water management facilities and practices had been in place throughout the reconstructed period, some of these periods of high salinity could have been reduced in duration or avoided.



TAYLOR RIVER SITE

MEAN MONTHLY SALINITY (psu) FROM HISTORICAL RECONSTRUCTION USING MIXED MLR ANALYSES

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	TOTAL BAY ANNUAL INFLOW (THOUSANDS ACRE-FEET/ YE
1970	0	9	13	18	34	20	14	19	21	17	18	18	**50**
1971	22	26	34	52	58	27	21	19	16	18	16	15	**20**
1972	15	15	17	21	20	10	10	15	11	11	9	8	162
1973	19	23	20	25	38	37	21	14	11	9	12	15	**84**
1974	9	17	26	46	68	49	22	18	10	13	13	15	**39**
1975	17	26	33	48	54	0	17	12	12	11	10	13	**71**
1976	11	13	17	28	22	13	9	12	10	7	10	12	139
1977	10	8	13	24	25	10	15	15	12	9	9	8	118
1978	8	7	8	10	15	10	6	5	4	5	0	3	127
1979	5	5	12	18	8	4	9	12	11	5	5	0	80
1980	7	6	4	12	16	17	12	10	6	5	5	5	115
1981	6	7	9	12	25	27	28	13	5	3	6	6	185
1982	7	11	17	19	12	9	7	8	7	1	0	4	168
1983	7	1	0	0	0	0	7	8	7	0	5	0	292
1984	8	10	14	18	22	21	13	10	0	5	8	9	178
1985	12	14	21	19	32	35	16	9	5	7	7	7	232
1986	8	10	11	16	23	27	10	6	9	12	12	13	205
1987	11	10	12	10	12	15	24	30	17	4	4	4	210
1988	0	7	10	21	22	0	3	1	0	0	1	3	278
1989	2	11	23	32	34	40	40	26	7	11	22	8	**83**
1990	15	31	43	50	53	47	24	19	4	6	15	6	**103**
1991	22	28	38	49	51	13	3	2	5	1	1	1	189
1992	3	7	12	27	37	27	1	1	0	1	0	1	222
1993	1	1	4	13	17	15	0	7	2	0	0	3	287
1994	5	1	1	5	23	10	10	13	1	0	0	0	394
1995	1	0	2	9	10	5	0	0	0	0	0	0	374
1996	2	8	7	10	19	7	0	1	0	0	0	0	214
1997	1	1	9	22	26	9	1	1	1	0	1	0	312
1998	0	0	1	1	9	16	8	4	4	0	1	0	281
1999	0	3	10	22	30	16	1	1	11	0	0	0	303
2000	0	0	1	3	15	22	13	8	8	0	0	1	323
2001	1	3	20	26	32	36	31	3	1	0	0	1	312
2002	1	1	1	14	25	16	1	1	0	1	1	1	256

KEY	SALINITY (PSU)	
	50+	HYPERSALINE++
	40 - 49	HYPERSALINE
	30 - 39	EUHALINE
	19 - 29	POLYHALINE
	6 -18	MESOHALINE
	0 - 5	OLIGOHALINE

Figure 52. Historical Reconstruction for Salinity Time Series at the Taylor River Site. Data from Marshall 2005. Top: time series of monthly estimates using a multiple linear regression model for station TR from 1970-1988 (using estimated stage values at station CP from 1970-1978) and observed data from TR after October 1988. Six periods of two consecutive years when monthly average salinity exceeded 30 psu are identified during the periods shown in the boxes (1970–1971, 1973–1975 and 1989–1992). Bottom: table format of same salinity time series at TR with color coding of salinity intervals and associated annual fresh water flow to northeastern Florida Bay.

The analysis also suggests that, in addition to monitoring flow into northeastern Florida Bay and salinity at the Taylor River site, the likelihood that monthly average salinity will exceed 30 psu can be anticipated or monitored by observing the stage of fresh water in the southern Everglades. Daily stage values at Craighead Pond (CP) fall below -1 feet NGVD29 during the years when monthly average salinity at Taylor River exceed 30 psu and may be used as a local indicator that inflow is critically low. A lowered water level gradient (<3') between stations P33 and P35 corresponds to regional drought periods during the historical reconstruction period (**Figure 53**).

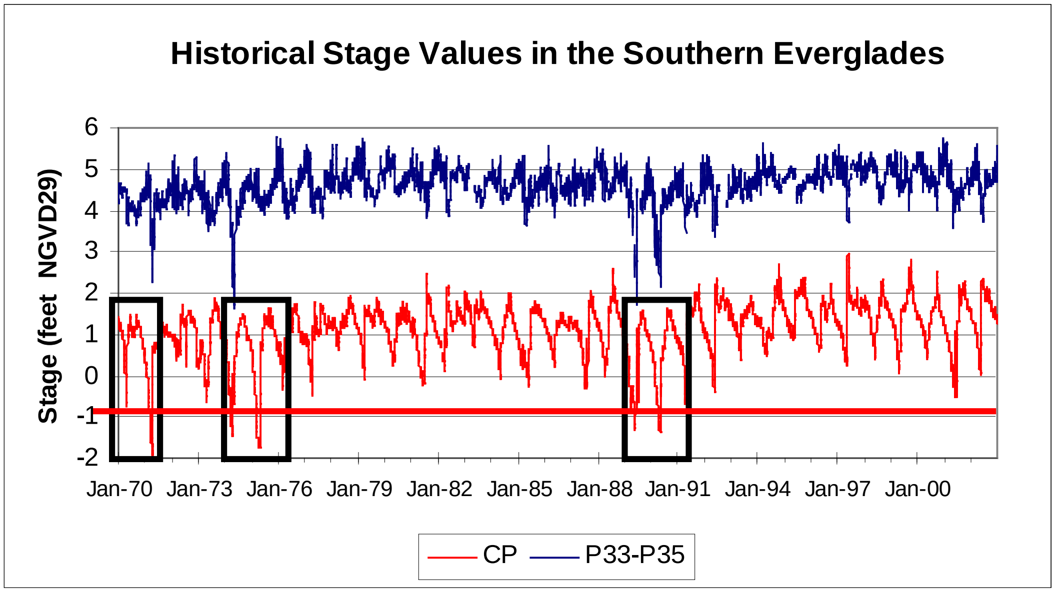


Figure 53. Daily Stage Values in the Southern Everglades over the Historical Reconstruction Period. The stages shown (from Marshall 2005) are used in the TR salinity model; data are based on observation except at Craighead Pond [CP] from the period 1970–1978, during which observation data are not available; estimates during this period were made based on a regression model (Marshall 2005). Daily stage values at CP that fall below -1 ft [NGVD29] during consecutive years also correspond to the time periods when salinity at Taylor River exceeded 30 psu; the gradient between P33 and P35 (within Shark River Slough) falls below 3 ft NGVD29 during regional drought periods, although low water levels at CP can occur more frequently.

Northeastern Florida Bay Modeling Results

The variation of monthly salinity between the lower portion of the Everglades-Florida Bay Transition Zone transect (inner Little Madeira Bay/mouth of Taylor River) to outer Little Madeira Bayand Eagle Key) reflects the influence of climatic variability and water management. Monthly mean salinity varied greatly (from 7 to 57 psu) over the 33-year historical reconstruction period at three estuarine sites (inner Little Madeira Bay, outer Little Madeira Bay, Eagle Key Basin). Conditions range from consistently hypersaline and euhaline in years of low flow and/or drought to dominantly polyhaline and mesohaline in years of normal and higher rainfall. Oligohaline conditions are not typical along this lower portion of the gradient and are restricted to the transition zone. The timing of hypersalinity in the estuary corresponded with high salinity in the transition zone. Persistent hypersaline periods existed in estuarine waters along the transect during periods of low fresh water flow when monthly average salinity exceeded 30 psu at the Taylor River site during consecutive years (see **Figure 54**; **Figure 25** and **Figure 26** in Chapter 4).

a.

INNER LITTLE MADEIRA BAY

MEAN MONTHLY SALINITY(psu) AS PREDICTED BY FATHOM MODEL

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	TOTAL BAY ANNUAL (THOUSANDS ACRE-
1970	50	48	47	51	51	44	37	39	40	38	39	42	**50**
1971	44	46	49	53	57	54	52	52	49	45	44	43	**20**
1972	43	44	45	45	39	22	14	19	24	26	28	30	162
1973	32	33	34	38	41	38	34	27	23	26	29	31	**84**
1974	32	35	38	41	42	40	37	36	38	40	42	44	**39**
1975	45	47	49	52	50	42	36	34	33	33	35	37	**71**
1976	38	39	41	44	41	28	23	22	18	22	27	30	139
1977	32	33	36	40	36	30	31	36	28	24	28	30	118
1978	31	31	32	34	34	32	32	31	25	21	23	27	127
1979	31	33	37	33	29	31	34	35	33	31	33	34	80
1980	35	37	39	41	42	35	28	27	27	28	29	28	115
1981	30	30	31	35	40	42	43	26	12	12	18	22	185
1982	26	29	30	27	25	19	17	19	19	18	17	19	168
1983	18	12	9	9	12	13	14	14	11	14	16	17	292
1984	22	25	28	31	31	27	22	18	16	18	23	27	178
1985	30	32	34	36	38	37	26	20	18	15	17	19	232
1986	21	24	25	26	32	31	24	19	21	28	33	32	205
1987	30	32	33	35	36	36	38	37	29	20	16	17	210
1988	20	23	29	35	35	22	10	7	8	12	16	21	278
1989	24	28	32	35	41	44	40	33	31	33	38	40	**83**
1990	43	47	49	50	49	46	47	42	35	35	37	41	**103**
1991	44	46	48	51	46	37	35	33	26	22	24	28	189
1992	31	33	35	37	40	29	19	19	17	20	20	21	222
1993	19	18	20	22	24	21	19	18	16	14	15	20	287
1994	22	19	18	20	22	22	24	23	14	12	13	12	394
1995	10	9	12	15	16	13	10	10	10	12	13	15	374
1996	16	17	19	22	22	16	13	13	13	10	12	17	214
1997	18	20	23	27	29	19	12	12	10	11	16	14	312
1998	12	12	9	10	14	19	23	23	17	14	14	15	281
1999	18	21	24	28	32	28	23	20	16	11	11	13	303
2000	12	12	14	18	23	23	20	16	13	12	15	18	323
2001	20	23	27	29	31	31	26	17	11	9	10	12	312
2002	13	15	19	24	26	18	10	10	12	16	21	23	256

b.

OUTER LITTLE MADEIRA BAY

MEAN MONTHLY SALINITY(psu) AS PREDICTED BY FATHOM MODEL

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	TOTAL BAY ANNUAL (THOUSANDS ACRE
1970	48	47	47	49	49	45	40	40	40	39	39	41	**50**
1971	43	45	46	50	53	52	51	51	49	45	43	43	**20**
1972	42	43	44	45	41	30	24	26	28	29	30	31	162
1973	33	33	35	37	40	38	36	32	28	29	31	32	**84**
1974	33	35	37	40	41	40	39	39	40	41	42	43	**39**
1975	44	45	47	49	49	44	40	38	36	35	36	37	**71**
1976	38	38	40	42	41	33	30	29	26	27	30	32	139
1977	33	33	36	39	37	34	35	38	33	30	31	32	118
1978	33	32	33	35	35	34	34	34	30	27	27	30	127
1979	32	34	36	35	33	35	36	37	35	33	34	35	80
1980	36	37	39	40	41	38	33	33	32	32	32	31	115
1981	32	32	33	36	39	41	42	32	22	20	22	25	185
1982	27	29	31	29	27	23	21	23	23	23	22	23	168
1983	22	17	15	14	16	18	19	19	18	19	20	21	292
1984	24	27	29	31	32	31	28	26	24	24	27	30	178
1985	32	33	35	36	38	38	31	28	26	24	24	25	232
1986	26	27	28	30	33	34	31	29	30	33	36	35	205
1987	33	34	35	36	37	37	39	40	35	29	25	25	210
1988	26	28	31	35	36	28	20	16	16	18	21	24	278
1989	27	30	32	35	40	43	41	38	37	38	40	42	**83**
1990	43	46	48	49	48	47	48	45	41	40	41	43	**103**
1991	45	46	47	49	47	42	40	38	33	29	29	31	189
1992	33	34	36	37	40	33	26	26	25	26	25	25	222
1993	24	22	24	25	27	26	25	25	23	21	21	25	287
1994	26	24	23	25	27	27	29	29	23	20	19	18	394
1995	17	16	18	19	20	18	16	16	16	16	16	18	374
1996	19	20	22	24	25	21	19	19	19	17	17	20	214
1997	21	22	25	28	30	24	20	19	17	17	20	19	312
1998	18	17	15	15	19	23	27	28	24	21	20	21	281
1999	22	24	26	29	33	31	28	26	23	18	17	17	303
2000	17	17	19	22	25	26	24	22	20	20	20	22	323
2001	23	25	28	30	32	32	30	25	20	17	17	18	312
2002	18	19	22	26	28	23	17	17	18	21	24	26	256

c.

EAGLE KEY- NE INTERIOR REGION

MEAN MONTHLY SALINITY(psu) AS PREDICTED BY FATHOM MODEL

YEAR	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL BAY ANNUAL INFLOW (THOUSANDS ACRE-FEET /YEAR)
1970	46	46	46	48	48	45	44	42	41	40	40	41	**50**
1971	42	43	44	46	49	50	50	50	48	46	43	42	**20**
1972	42	42	43	44	43	39	34	34	33	32	32	33	162
1973	34	34	35	37	39	39	38	36	34	32	32	33	**84**
1974	33	35	37	39	41	41	41	41	41	42	42	43	**39**
1975	43	44	45	47	47	45	43	41	39	38	38	38	**71**
1976	38	38	39	41	41	38	36	35	33	32	33	34	139
1977	34	34	36	38	39	38	39	40	39	36	35	34	118
1978	34	34	34	36	36	35	36	36	35	33	32	33	127
1979	33	34	36	37	37	38	38	38	38	36	36	37	80
1980	37	37	38	39	40	40	39	38	37	36	35	34	115
1981	34	35	35	36	39	40	41	38	31	27	27	27	185
1982	29	30	31	30	29	27	25	26	27	28	27	27	168
1983	26	23	21	20	21	23	23	25	25	24	25	25	292
1984	27	29	30	32	34	34	34	34	32	31	31	32	178
1985	33	34	35	37	38	38	37	37	35	33	31	31	232
1986	30	31	31	33	35	37	39	39	38	39	39	38	205
1987	36	36	36	37	38	39	41	43	42	38	34	32	210
1988	32	32	34	36	37	34	29	25	23	24	25	27	278
1989	29	31	33	36	39	42	43	43	42	42	42	43	**83**
1990	44	46	47	48	48	48	49	49	47	45	45	45	**103**
1991	45	46	47	48	48	46	45	43	40	36	33	34	189
1992	34	35	37	38	40	37	34	33	32	31	30	30	222
1993	29	27	28	29	30	30	31	31	30	28	28	29	287
1994	30	29	29	31	32	33	34	35	32	28	26	25	394
1995	23	23	24	24	25	24	23	22	21	20	20	21	374
1996	22	23	24	26	27	26	25	25	25	23	22	23	214
1997	24	25	26	29	31	30	28	27	25	23	24	24	312
1998	23	23	21	21	23	26	30	32	30	28	27	26	281
1999	27	27	28	31	33	33	32	32	29	25	22	22	303
2000	23	23	24	26	28	29	29	29	28	27	26	26	323
2001	26	28	29	31	33	34	34	32	29	25	23	23	312
2002	24	24	25	28	30	28	25	24	25	26	28	28	256

KEY	SALINITY (PSU)	
	50+	HYPERSALINE++
	40 - 49	HYPERSALINE
	30 - 39	EUHALINE
	19 - 29	POLYHALINE
	6 - 18	MESOHALINE
	0 - 5	OLIGOHALINE

Figure 54. Monthly Salinity Conditions within the Florida Bay portion of the Everglades-Florida Bay gradient. Output from the FATHOM model (ECT 2005) was used to develop salinity-flow illustrations for the reconstructed historical conditions at three locations along the Taylor River–Little Madeira gradient within Florida Bay (see **Figure 23**). The outer Little Madeira values (panel b) were obtained by averaging data from panels a and c; the years within the boxes correspond to the periods when monthly average salinity at the Taylor River site exceeded 30 psu during consecutive years; when low flow conditions (< 105 acre-feet /year) occur for two or more consecutive years, then hypersaline conditions (> 40 psu) persist for during the next year's dry season).

During those periods, salinity conditions downstream in Little Madeira Bay, Eagle Key Basin and northeastern Florida Bay were considerably higher and persisted longer than at the Taylor River Site. Results indicated that whereas salinity at the Taylor River site during low-flow periods exceeded 30 psu for 2-5 months, salinity in Little Madeira Bay and Eagle Key Basin remained above 30 psu for a year or more and were above 40 psu for several months. Periods of prolonged marine to hypersaline conditions can result in a loss of estuarine function within Florida Bay, including the loss of *Halodule wrightii* and negative impacts on fish and other fauna downstream in Little Madeira Bay and Eagle Key Basin (see Chapter 4).

FATHOM results also indicate that hypersaline conditions occur during these same periods in other northeastern and central coastal basins such as Long Sound, Joe Bay and Trout Cove (ECT 2005). Thus, during years when monthly average salinity at the Taylor River site exceeded 30 psu for consecutive years, a substantial part of Florida Bay, including regions that receive direct inflow and that normally have estuarine salinity, experienced hypersaline conditions. The euhaline and hypersaline conditions associated with calendar years of low inflow (**Figure 54)** often persist into a substantial portion of the following calendar year's dry season, and estuarine conditions may not return until the summer or fall of the following year when inflow increases. This timing effectively increases the period of elevated salinity experienced in Florida Bay and indicates that timing of inflow is an important consideration.

Transport time is a widely-used metric in biological and hydrologic studies and can be analyzed using the FATHOM model to estimate the time needed for water to move throughout the system. Turnover time, which is the rate at which an estuary "flushes," or exchanges its water and/or materials such as nutrients, can partially determine the estuary's trophic state and health. The turnover times may be used to compare water exchange differences among Florida Bay's many sub-basins. Turnover time is calculated by FATHOM on a monthly basis for each of the 41 basins and is defined as the monthly average volume of water in a basin divided by the monthly total influx of water into the basin (including flood tides, rainfall and runoff); results are expressed in days (ECT, Inc. 2005). Turnover time (**T_T)** is mathematically equivalent to the classically defined hydraulic retention time of a basin defined as

$$T_T = V/Q$$

where **V** is the volume of the basin and **Q** is the water flux.

Turnover times for the FATHOM basins of Florida Bay range from a few days up to almost six months (ECT, Inc. 2005). Inspection of turnover times and salinity in Florida Bay indicates that periods of rapid increase in salinity coincide with periods of slow turnover (high turnover times) (ECT, Inc. 2005). Basins with slow turnover are more susceptible to development of hypersaline conditions during periods when evaporation is greater than rainfall. FATHOM estimates indicate that in Florida Bay, such basins are found primarily in the eastern region (**Figure 55**). Eastern basins (Long Sound, Joe Bay, Little Madeira Bay, Park Key and Duck Key shown) also have turnover times that are more seasonally variable than those of other Bay areas.

Over the historical reconstruction period, the minimum value for turnover times in Little Madeira Bay is 18 days, the median value is 39 days, and the maximum is 82 days. The values for Eagle Key basin (shown as Park Key) are 31 minimum, 58 median and 129 maximum. The previously identified low flow years (1970–1971, 1973–1975 and 1989–1990) exhibit relatively slow turnover times in the dry season in the coastal embayments Little Madeira, Joe Bay and Long Sound. In those years, these embayments experience reduced "flushing," with the attendant increases in salinity and likely increases in retention of nutrients and other materials.

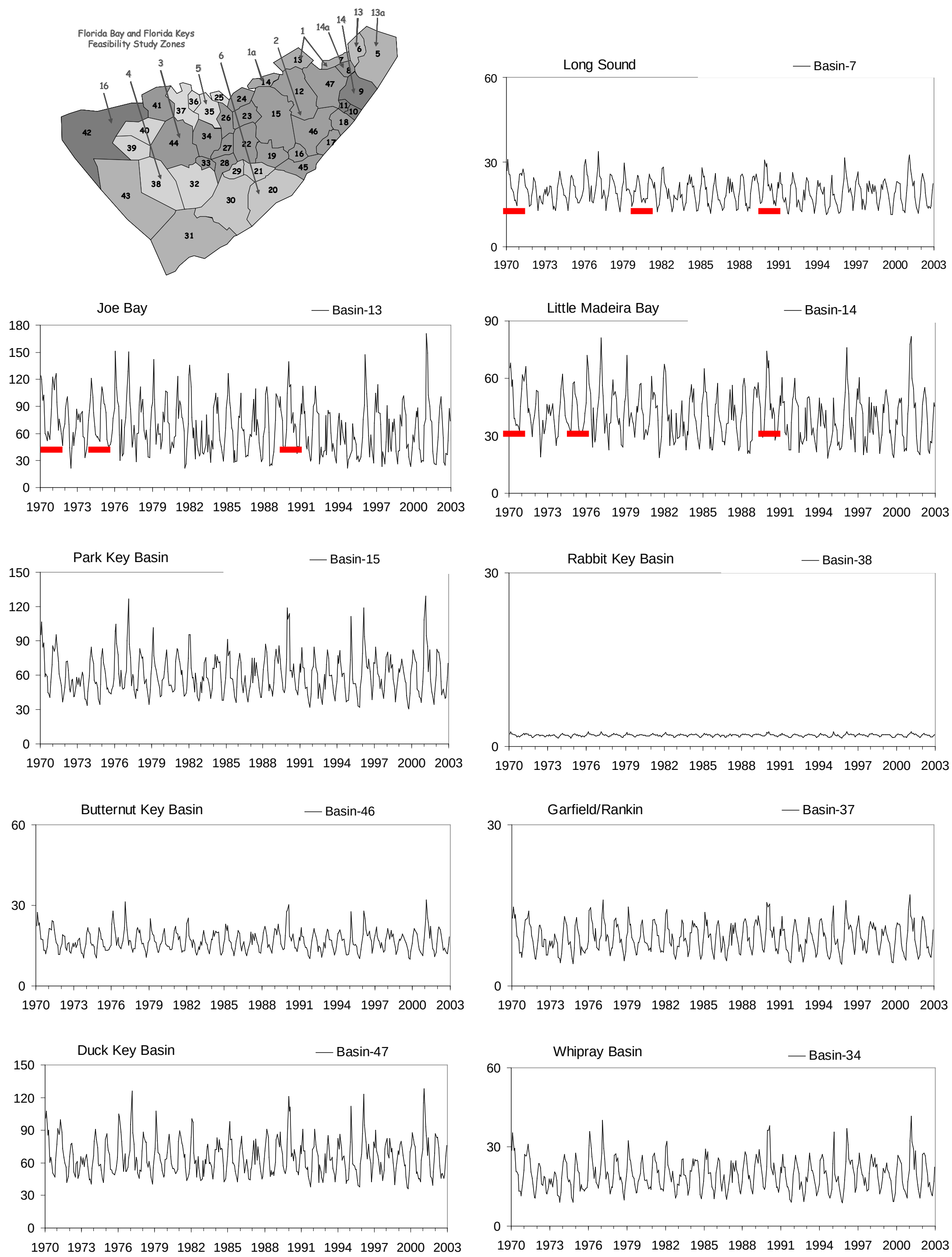


Figure 55. Time Series of Monthly Values of Simulated Turnover Times (Days) for Nine Selected FATHOM Basins (the map on the upper left shows the location of the FATHOM basins; the eastern basin [Long Sound, Joe Bay, Little Madeira Bay, Park Key and Duck Key] shows the most variable turnover rates; the red lines are placed to highlight the relatively high turnover times in the coastal embayments in the wet season during previously identified low inflow years).

Consistency between Taylor River MLR Model and the FATHOM Model

Salinity predictions from the Taylor River MLR and FATHOM were compared along Transition Zone – northeast Florida Bay transect sites. Of the possible 384 monthly predictions that represented the historical period (32 years x 12 months), 25 observations had mean monthly salinity values between 25 and 35 psu at the Taylor river site (**Table 12**).

Table 12. Salinity Predictions of Taylor River MLR Model (at Taylor River site) and of FATHOM Model (at Little Madeira Bay and Eagle Key basin) during Periods of Salinity Stress (number of months of salinity between 25 psu and 35 psu at Taylor River site is 25 out of a possible 384 for period 1970–2000; when salinity values at the Taylor River site are near 30 psu, then the salinity values along the gradient in northeastern Florida Bay are near 40 psu; the low Spearman rank-order correlation probably reflects differential modeling errors per time point for both models).

For TR values between 25-35

	TR	Little Madeira	Eagle
N of cases	25	25	25
Minimum	24.5	25.8	30.8
Maximum	34.9	54.1	49.8
Range	10.4	28.3	19.0
Sum	711.1	975.5	989.1
Median	27.2	38.2	38.8
Mean	28.4	39.0	39.6
95% CI Upper	29.7	42.1	41.6
95% CI Lower	27.1	35.9	37.5
Std. Error	0.6	1.5	1.0
Standard Dev	3.2	7.5	5.0
Variance	10.0	56.3	24.7
C.V.	0.1	0.2	0.1
Skewness(G1	0.8	0.0	0.1
SE Skewness	0.5	0.5	0.5
Kurtosis(G2)	-0.8	-0.8	-0.6
SE Kurtosis	0.9	0.9	0.9
95%	34.0	50.0	47.1

Spearman Correlation Matrix

TR	Eagle	Little Madeira
	0.18	0.20

Number of Observations: 25

These values were consistent with the mean and median values of near 30 psu for the Taylor River MLR model and with FATHOM output of approximately 40 psu for the downstream sites Little Madeira Bay and Eagle Key basin. The time series of the salinity over the 33-year historical period along the gradient illustrates that the two modeling approaches generally yielded consistent results, given position along the flow path (upstream to downstream) (**Figure 56**).

One exception occurred during the period from 1978 through 1981. The Taylor River MLR model's reconstruction shows fairly low salinity, with little relative difference between wet season and dry season, yet the FATHOM model shows fairly elevated salinity in Little Madeira Bay and Eagle Key during the same period. The Taylor River MLR model's salinity finding is consistent with the water level data at nearby Craighead Pond (CP) and with data from the P33-P35 gradient within Shark Slough.

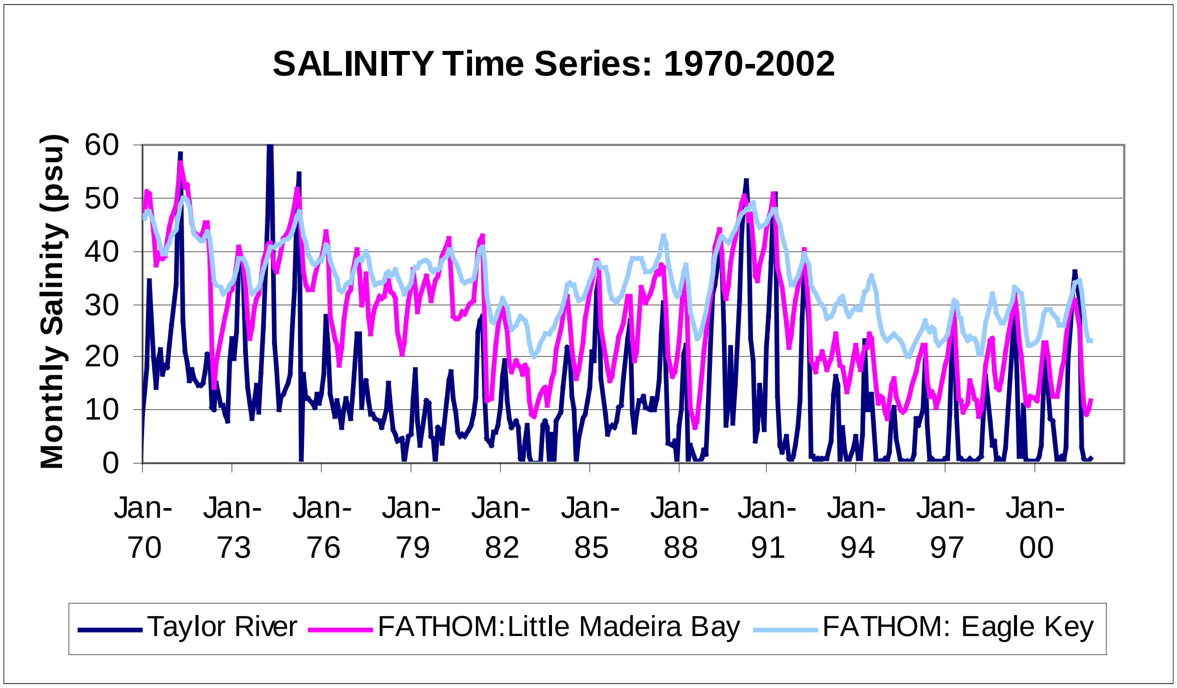


Figure 56. Consistency between Salinity Time Series by the MLR Model (dark blue for Taylor River site) and Salinity Time Series by the FATHOM Model (pink for Little Madeira Bay, light blue for Eagle Key basin) along the transition zone – Bay transect (1970–2002).

The FATHOM model's predictions are consistent with flow data from the C-111 Canal and the Taylor Slough Bridge. Observational data are very limited, both spatially and temporally, during this time period, but the available data from various archived sources, as reported by Orlando et al. (1997) indicate that salinity (reported as combined average seasonal salinity), varied from 10 to near 40 psu in the coastal embayments (Little Madeira, Madeira Bay and Terrapin). The data could therefore support either or both model results. The reasons for the differences in salinity predictions between the two models and the difference with respect to the field data for this period are unknown. Further analyses will be presented, based on short-term (three-month) flow data and Taylor River salinity.

Structural Flows and Craighead Pond Stage During High Salinity Periods

Analyses were conducted to establish a connection between inflows to northeastern Florida Bay and periods when monthly average salinity at the Taylor River site exceeded 30 psu during consecutive years. Inflows to northeastern Florida Bay were calculated based on measures of freshwater flow at Taylor Slough Bridge (TSB) and at upstream water management structures S-18C and S-197, using the FATHOM historical reconstruction flow inputs (**Figure 57**). During and prior to periods when monthly average salinity at the Taylor River site exceeded 30 psu during consecutive years, the total average annual inflow to northeastern Florida Bay was less than 105,000 ac-ft per year for two consecutive years (**Figure 57**). The average annual flow directly into Little Madeira Bay in years when monthly average salinity at the Taylor River site exceeded 30 psu for multiple years in succession was less than 10,000 ac-ft per year (**Figure 58**). A more detailed analysis of flows indicated that monthly average salinity above 30 psu could occur even during years when total annual inflow was greater than 105,000 ac-ft per year. Such conditions occurred when 1) salinity at Taylor River at the beginning of the dry season were above 19 psu and 2) the preceding three-month total inflow into northeastern Florida Bay for any given month during the period January through March was less than 7,000 ac-ft (**Figure 59**). This finding illustrates the importance of considering the salinity impact of the timing of inflow in the transition zone.

TOTAL INFLOW INTO NE FLORIDA BAY (THOUSANDS ACRE-FEET)

YEAR	MONTH JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL TOTAL
1970	**2.4**	**1.0**	**0.3**	**0.0**	**2.9**	**12.2**	**17.0**	**0.8**	**3.6**	**8.7**	**1.2**	**0.0**	**50.0**
1971	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**9.3**	**0.2**	**0.3**	**5.6**	**2.9**	**0.9**	**1.3**	**20.5**
1972	0.0	0.0	0.0	4.4	16.2	79.3	29.1	11.3	8.5	7.4	5.4	0.1	161.8
1973	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**7.0**	**11.2**	**36.3**	**22.0**	**6.5**	**0.5**	**0.3**	**83.9**
1974	**0.0**	**0.0**	**0.0**	**2.3**	**0.0**	**7.5**	**12.3**	**7.6**	**4.2**	**5.1**	**0.0**	**0.0**	**39.0**
1975	**0.0**	**0.0**	**0.0**	**0.0**	**8.6**	**16.1**	**20.0**	**14.3**	**7.5**	**4.0**	**0.3**	**0.0**	**70.9**
1976	0.0	0.0	0.0	0.0	6.3	47.8	5.3	34.0	36.3	6.2	3.4	0.0	139.2
1977	0.0	0.0	0.0	0.0	16.7	26.3	1.8	4.9	58.7	7.5	0.8	1.5	118.1
1978	0.3	5.7	0.5	4.0	0.9	7.9	8.5	13.8	45.0	34.1	6.4	0.0	127.2
1979	0.0	0.0	0.0	21.2	14.0	3.2	7.0	1.2	21.5	6.6	0.2	5.1	80.0
1980	0.1	0.0	0.0	0.1	0.3	34.5	20.6	14.1	22.4	5.9	8.4	8.4	114.8
1981	0.0	9.3	0.1	0.0	0.0	0.0	0.3	81.4	60.8	29.2	3.4	0.0	184.5
1982	0.0	0.0	0.0	4.4	3.6	33.8	4.2	18.0	24.4	41.8	29.3	8.2	167.8
1983	18.4	42.1	32.1	26.9	3.9	29.1	11.5	32.4	59.1	4.3	31.1	1.2	292.1
1984	0.0	0.0	0.0	0.0	10.7	21.7	29.6	34.3	46.9	29.3	4.1	1.9	178.4
1985	2.9	1.2	1.0	0.6	0.2	2.2	60.3	28.9	52.0	51.7	24.9	5.7	231.5
1986	9.9	0.8	9.9	8.1	0.0	27.1	51.5	36.5	39.5	6.4	7.9	7.6	205.1
1987	8.2	0.9	5.9	0.2	9.3	6.5	9.5	19.4	31.4	54.8	45.3	19.1	210.4
1988	11.9	1.7	0.4	0.0	5.0	56.4	55.1	65.0	41.5	33.0	4.3	3.3	277.5
1989	**2.2**	**0.9**	**0.4**	**0.2**	**0.2**	**0.7**	**19.8**	**27.4**	**18.4**	**8.1**	**2.5**	**2.5**	**83.3**
1990	**1.9**	**0.8**	**0.4**	**0.2**	**6.6**	**7.0**	**6.0**	**32.2**	**17.9**	**22.5**	**5.3**	**2.4**	**102.9**
1991	2.5	1.9	0.9	0.1	18.3	28.3	12.8	20.6	49.7	42.7	8.5	2.9	189.2
1992	2.1	2.6	2.5	0.8	0.2	47.5	29.9	36.7	43.0	23.5	26.4	6.4	221.6
1993	27.0	7.8	8.5	5.0	7.9	32.6	30.0	31.3	43.5	62.0	24.4	6.8	286.8
1994	9.3	25.3	16.5	14.8	14.4	26.2	4.3	48.0	86.1	58.0	43.5	47.2	393.7
1995	42.3	23.4	13.1	10.8	21.0	48.4	47.0	54.1	43.2	33.8	24.6	12.2	374.0
1996	10.1	3.5	1.4	0.6	13.8	36.5	22.5	24.6	32.2	57.1	9.3	3.0	214.5
1997	1.8	1.0	0.7	0.5	3.5	79.9	39.6	55.1	62.6	20.6	2.6	44.0	312.0
1998	12.7	26.5	31.7	14.9	14.1	6.3	9.9	30.4	55.4	42.3	32.2	5.0	281.5
1999	11.1	3.7	0.7	0.2	0.5	21.0	22.2	41.0	60.7	78.3	36.5	27.0	302.8
2000	36.4	23.2	6.2	7.2	0.6	14.8	29.4	62.5	60.7	65.0	9.7	7.4	323.1
2001	0.2	0.0	0.0	0.2	1.2	9.3	28.3	60.0	64.5	70.0	51.6	26.7	312.1
2002	15.9	2.6	0.6	0.2	6.5	45.4	75.3	42.1	38.5	16.2	2.0	10.7	256.2

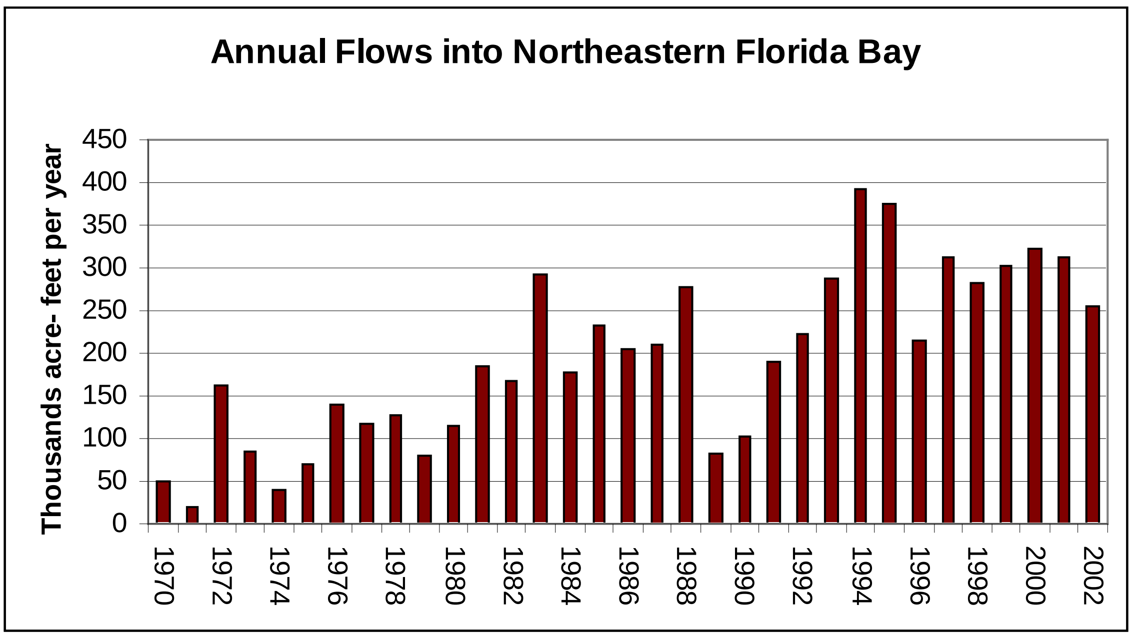


Figure 57. Inflows to Northeast Florida Bay. Data shown are FATHOM historical reconstruction flow inputs based on structure flows and water budget information (ECT, Inc. 2005). Years highlighted in orange (top panel) correspond to periods when the total annual flow was less than 105,000 ac-ft for Florida Bay for two consecutive years and correspond to periods previously identified as entailing sustained impacts to SAV resources in the transition zone. A year in which such an inflow level occurred for one year is highlighted in yellow. The majority of wet season inflows typically occurred June through November. Salinity conditions can exceed 30 psu at the Taylor River site in years when annual inflow is not low but inflows are delayed, such as 1991; the timing and duration of inflow may be important for some biota and should be considered in future restoration activities.

TOTAL INFLOW INTO LITTLE MADEIRA BAY (THOUSANDS ACRE-FEET)

YEAR	MONTH JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL TOTAL
1970	**0.2**	**0.1**	**0.0**	**0.0**	**0.3**	**1.0**	**1.4**	**0.1**	**0.3**	**0.8**	**0.1**	**0.0**	**4.3**
1971	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.9**	**0.0**	**0.0**	**0.5**	**0.3**	**0.1**	**0.1**	**2.0**
1972	0.0	0.0	0.0	0.4	1.6	7.4	2.4	1.0	0.7	0.6	0.5	0.0	14.7
1973	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.7**	**1.0**	**3.3**	**1.7**	**0.5**	**0.0**	**0.0**	**7.3**
1974	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.8**	**1.1**	**0.6**	**0.3**	**0.5**	**0.0**	**0.0**	**3.4**
1975	**0.0**	**0.0**	**0.0**	**0.0**	**0.9**	**1.6**	**1.8**	**1.4**	**0.6**	**0.3**	**0.0**	**0.0**	**6.6**
1976	0.0	0.0	0.0	0.0	0.6	4.1	0.3	3.1	3.0	0.5	0.3	0.0	11.8
1977	0.0	0.0	0.0	0.0	1.6	2.1	0.1	0.4	5.0	0.6	0.0	0.1	9.9
1978	0.0	0.6	0.0	0.4	0.1	0.7	0.7	1.2	3.8	3.2	0.6	0.0	11.4
1979	0.0	0.0	0.0	2.1	1.2	0.2	0.6	0.1	2.0	0.5	0.0	0.5	7.2
1980	0.0	0.0	0.0	0.0	0.0	3.1	1.8	1.3	1.9	0.5	0.8	0.8	10.1
1981	0.0	0.9	0.0	0.0	0.0	0.0	0.0	7.1	5.2	2.3	0.2	0.0	15.8
1982	0.0	0.0	0.0	0.4	0.3	2.7	0.3	1.5	2.1	3.6	2.5	0.6	14.0
1983	1.6	3.9	3.2	2.7	0.4	2.7	1.0	3.1	5.6	0.3	3.0	0.1	27.6
1984	0.0	0.0	0.0	0.0	1.0	1.8	2.6	3.3	4.4	2.7	0.4	0.2	16.4
1985	0.3	0.1	0.1	0.1	0.0	0.2	5.6	2.6	4.9	5.0	2.4	0.6	21.9
1986	1.0	0.1	1.0	0.8	0.0	2.5	5.0	3.6	3.8	0.6	0.8	0.8	19.9
1987	0.8	0.1	0.6	0.0	0.9	0.6	0.9	1.7	3.0	5.1	4.5	1.9	20.1
1988	1.2	0.2	0.0	0.0	0.5	5.2	5.1	5.8	3.9	3.1	0.4	0.3	25.7
1989	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**1.9**	**2.6**	**1.7**	**0.7**	**0.2**	**0.2**	**7.8**
1990	**0.2**	**0.1**	**0.0**	**0.0**	**0.7**	**0.6**	**0.4**	**3.1**	**1.6**	**2.1**	**0.5**	**0.2**	**9.6**
1991	0.2	0.2	0.1	0.0	1.8	2.6	1.1	1.9	4.7	3.8	0.7	0.3	17.3
1992	0.2	0.2	0.2	0.1	0.0	4.4	2.5	3.2	3.8	2.2	2.5	0.6	20.0
1993	2.6	0.7	0.7	0.4	0.7	3.0	2.5	2.6	3.7	5.5	2.1	0.5	25.0
1994	0.8	2.4	1.4	1.4	1.3	2.4	0.4	3.9	7.5	4.8	3.5	4.1	33.7
1995	3.7	2.0	1.2	1.1	1.9	4.3	3.9	4.7	3.6	2.6	2.0	0.9	31.9
1996	0.8	0.3	0.1	0.1	1.3	3.2	1.9	2.0	2.7	4.7	0.7	0.3	18.0
1997	0.2	0.1	0.1	0.1	0.3	6.5	3.3	4.6	5.1	1.8	0.2	3.5	25.7
1998	0.9	2.3	2.8	1.3	1.3	0.6	0.8	2.6	4.7	3.3	2.8	0.4	24.0
1999	0.9	0.3	0.1	0.0	0.0	1.9	2.0	3.5	5.1	6.0	2.8	2.1	24.7
2000	2.8	1.8	0.6	0.7	0.1	1.4	2.6	5.2	5.0	5.0	0.8	0.7	26.6
2001	0.0	0.0	0.0	0.0	0.1	0.9	2.6	5.1	5.4	5.4	3.9	2.2	25.6
2002	1.3	0.2	0.1	0.0	0.6	4.2	6.0	3.4	3.1	1.3	0.2	1.0	21.5

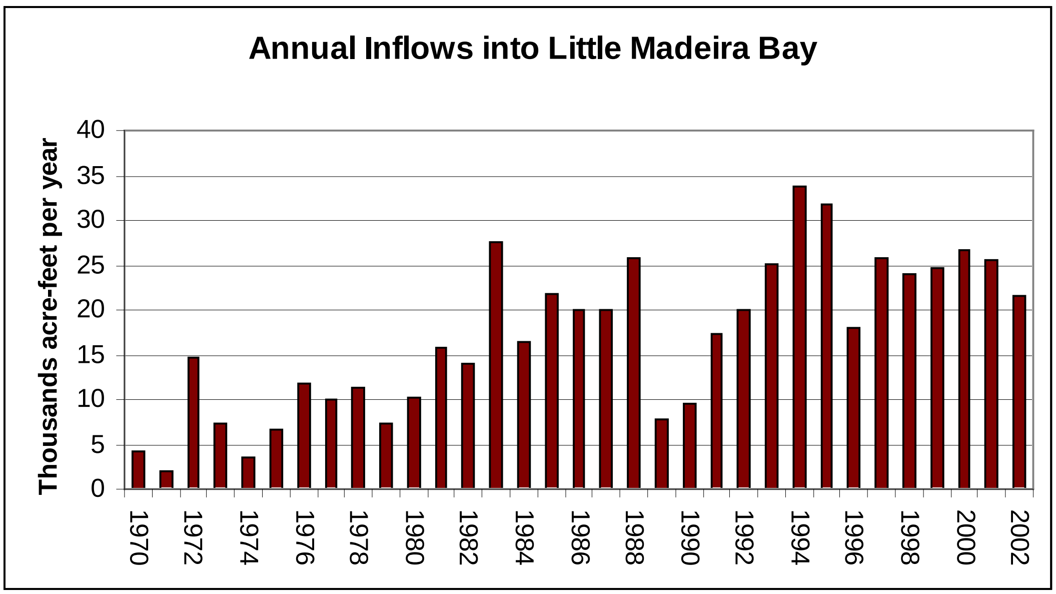


Figure 58. Inflows to Little Madeira Bay. Data shown are FATHOM historical reconstruction flow inputs based on structure flows and water budget information (ECT, Inc. 2005). Years highlighted in orange (top panel) correspond to periods in which the total annual flow was <10,000 ac-ft per year for Little Madeira Bay for two consecutive years and correspond to periods previously identified as entailing sustained impacts to SAV resources in the transition zone. Years in which such an inflow level occurred for one year are highlighted in yellow. The majority of wet season inflows typically occurred June through November. Salinity conditions can exceed 30 psu at the Taylor River site in years when annual inflow is not low but inflows are delayed, such as 1991; the timing and duration of inflow may be important for some biota and should be considered in more detail in future restoration activities.

PRIOR THREE MONTH SUM OF NORTHEASTERN FLORIDA BAY FLOWS (THOUSANDS ACRE-FEET)

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1970	.	.	.	3.7	1.3	3.1	15.1	32.1	30.0	21.4	13.0	13.5
1971	9.9	1.2	0.0	0.0	0.0	0.0	9.3	9.5	9.7	6.0	8.8	9.4
1972	5.1	2.2	1.3	0.0	4.4	20.5	99.9	124.6	119.7	48.9	27.2	21.4
1973	13.0	5.6	0.2	0.1	0.0	0.0	7.0	18.2	54.5	69.5	64.9	29.0
1974	7.3	0.7	0.3	0.0	2.3	2.3	9.9	19.8	27.4	24.1	16.9	9.3
1975	5.1	0.0	0.0	0.0	0.0	8.6	24.7	44.7	50.4	41.8	25.9	11.9
1976	4.3	0.3	0.0	0.0	0.0	6.3	54.0	59.3	87.0	75.5	76.5	45.9
1977	9.6	3.4	0.0	0.0	0.0	16.7	43.0	44.7	32.9	65.3	71.1	67.0
1978	9.8	2.6	7.5	6.5	10.2	5.4	12.8	17.3	30.2	67.4	93.0	85.6
1979	40.5	6.4	0.0	0.0	21.2	35.2	38.4	24.2	11.4	29.7	29.3	28.3
1980	11.9	5.4	5.2	0.2	0.1	0.3	34.8	55.4	69.2	57.2	42.4	36.7
1981	22.7	16.8	17.6	9.4	9.4	0.1	0.0	0.3	81.7	142.5	171.4	93.4
1982	32.6	3.4	0.0	0.0	4.4	8.0	41.8	41.6	56.0	46.7	84.3	95.6
1983	79.4	55.9	68.7	92.6	101.1	62.9	59.9	44.5	73.0	103.1	95.9	94.5
1984	36.5	32.2	1.2	0.0	0.0	10.7	32.4	62.0	85.6	110.7	110.5	80.2
1985	35.3	8.9	6.0	5.1	2.8	1.8	3.0	62.7	91.3	141.1	132.5	128.6
1986	82.3	40.5	16.4	20.6	18.8	18.0	35.1	78.6	115.1	127.5	82.3	53.7
1987	21.9	23.6	16.7	15.0	7.0	15.4	15.9	25.3	35.4	60.3	105.5	131.5
1988	119.2	76.3	32.6	13.9	2.1	5.4	61.4	116.5	176.5	161.5	139.5	78.9
1989	40.7	9.8	6.4	3.5	1.4	0.7	1.1	20.8	48.0	65.6	53.9	29.0
1990	13.1	6.9	5.1	3.0	1.3	7.1	13.8	19.5	45.2	56.0	72.5	45.6
1991	30.2	10.2	6.8	5.3	2.9	19.3	46.7	59.5	61.7	83.1	112.9	100.8
1992	54.1	13.5	7.6	7.2	5.9	3.5	48.5	77.6	114.1	109.6	103.2	93.0
1993	56.3	59.8	41.1	43.3	21.3	21.4	45.5	70.5	93.9	104.8	136.7	129.9
1994	93.3	40.6	41.4	51.1	56.6	45.7	55.4	44.9	78.5	138.4	192.2	187.7
1995	148.8	133.1	112.9	78.8	47.3	44.9	80.2	116.4	149.5	144.3	131.1	101.6
1996	70.7	46.9	25.8	15.0	5.5	15.7	50.8	72.7	83.6	79.3	113.9	98.5
1997	69.4	14.1	5.8	3.5	2.3	4.8	83.9	123.0	174.6	157.4	138.3	85.8
1998	67.2	59.3	83.3	71.0	73.2	60.7	35.3	30.3	46.6	95.7	128.1	129.9
1999	79.5	48.2	19.7	15.5	4.6	1.4	21.7	43.7	84.2	123.9	180.0	175.5
2000	141.8	99.9	86.6	65.8	36.6	14.0	22.7	44.8	106.7	152.6	188.2	135.4
2001	82.1	17.3	7.6	0.2	0.2	1.4	10.7	38.8	97.6	152.8	194.5	186.1
2002	148.3	94.3	45.3	19.2	3.5	7.3	52.1	127.2	162.9	155.9	96.9	56.7
MAXIMUM	148.8	133.1	112.9	92.6	101.1	62.9	99.9	127.2	176.5	161.5	194.5	187.7
MINIMUM	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	9.7	6.0	8.8	9.3

Figure 59. Impact of Dry-Season Flows on Salinity Stress in the Transition Zone. Numbers indicate flows to Northeastern Florida Bay (thousands of ac-ft); red numbers indicate periods when salinity in transition zone is 19 psu or above 9polyhaline conditions); blue areas correspond to months when previous three-month total flows to northeast Florida Bay were 7,000 ac-ft or less; boxed areas show periods when both of these conditions occur simultaneously during the months January - March; these boxed times correspond to periods when monthly average salinity exceeded 30 psu in one year: 1985 and 2001 or during two or more consecutive years, (as indicated by yellow shading). Thus, a combination of polyhaline (or higher) salinity and low inflow at the onset of the dry season (January - March) leads to exceedance of the 30 psu salinity condition at the Taylor River site later in the year; the period 1978–1981, previously identified as having relatively low inflows to northeast Florida Bay, does not show polyhaline conditions until later in the dry season.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Analysis of the 33-year historical reconstruction of salinity for the Taylor River site indicated that monthly average salinity exceeded 30 ppt during 12 of these years. In some cases, these high-salinity events occurred for two, three or four years in succession.
- During years when monthly average salinity exceeded 30 psu at the Taylor River site, and these conditions occurred in consecutive years, elevated salinity, including hypersaline conditions, occurred along the entire transition zone – Florida Bay transect. The magnitude and duration of high salinity events in the estuarine portion of the transect exceeded those in the wetland portion of the transect.
- The frequency and duration of these high-salinity events under reconstructed historical conditions could potentially have been reduced if current water management facilities and operational procedures had been in place throughout the reconstructed period
- Based on estimates from hydrologic models, an annual inflow of 105,000 ac-ft to northeastern Florida Bay is generally sufficient to avoid conditions that allow monthly average salinity at the Taylor River site to exceed 30 psu.
- Monthly average salinity exceeded 30 psu at the Taylor River site during periods of low water levels and low freshwater flow in the southeastern Everglades – typically during the dry season. More detailed analysis of these conditions indicated that if monthly average salinity at the Taylor River site was 19 psu or greater (polyhaline conditions) during any of the months from January through March, then (based on typical dry season rainfall patterns) salinity can be expected to exceed 30 psu during the subsequent three months.
- Modeling analyses suggest that maintenance of three-month (January through March) total inflow above 7,000 ac-ft should be sufficient to maintain monthly average salinity at the Taylor River site below 30 psu and thus protect resources in Taylor River and northeastern Florida Bay from experiencing impacts due to salinity stress later that year.
- Stage at the Craighead Pond site (CP) provides an additional local indicator that can be used to identify years in which critically low total annual inflow is anticipated. Periods when monthly average salinity at the Taylor River site exceeds 30 psu correspond to times when daily stage at CP falls below -1ft (relative to NGVD29) for any two consecutive years.
- Flows and stages sufficient to prevent monthly average salinity maxima at the Taylor River site below 30 psu should protect widgeon grass (*Ruppia*), SAV and macroalgal habitat, and associated resources along the transition zone gradient and also protect seagrass communities and associated biota in northeastern Florida Bay.

Recommendations for Future Work

The analyses presented in this report are based on best available information. The need for additional work is recognized. The following list summarizes limitations in the information presented and gives recommendations for future work:

- A monitoring program consistent with the MFL recommendations and objectives should be instituted. Current monitoring of hydrologic conditions, water quality and SAV in the southern Everglades and northeastern Florida Bay should be modified to improve information on the Everglades–Florida Bay salinity transition zone. Continued salinity monitoring should occur at the Taylor River site as well as at sites along the Little Madeira transect within Florida Bay. Creek flow monitoring (currently performed by USGS) should continue and possibly be expanded to quantify the ungauged flow. Efforts should be initiated to identify additional ecologic resources in coastal rivers, ponds and wetlands that may need to be monitored to provide better assessment of resource impacts.

- *Ruppia maritima* and other transition SAV, along with salinity, should be routinely monitored at several locations within the transition zone and within the coastal embayments of Florida Bay. Research on the response *Ruppia* to salinity levels and variability, including effects on seed production, seed bank viability, and reproductive success should be implemented. The dynamic model of Florida Bay SAV should be expanded to include *Ruppia*. These monitoring data should be used to develop a dynamic model of *Ruppia*. The habitat value of *Ruppia* and other SAV of the transition zone should be quantitatively assessed.
- Given the commercially valuable and ecologically sensitive resources in the central basins of Florida Bay (such as pink shrimp), further work should be pursued to quantify and predict inflow and its effects on salinity and biological resources. Ecologic resources and hypersalinity within these regions were not considered as a basis for the MFL criteria in this report because with available models, a direct link to inflow could not be established. Linking flows and salinity was difficult because the total inflow is low and largely ungauged and the hydrodynamics of Florida Bay are complex. The models currently being developed as part of the CERP Florida Bay and Florida Keys Feasibility Study (FBFKFS) should be used in future evaluations.
- The spatial distribution and seasonal timing of inflow to northeastern Florida Bay should be included as elements to be investigated further in the FBFKFS and CERP projects. The final MFL criteria should be included as systemwide performance measures and should be considered in all projects and analyses that influence inflows into Florida Bay.
- Consideration should be given in the future to determination of the effects of potential consequences of Florida Bay MFL criteria on Shark Slough flows, the Whitewater Bay estuarine system and western Florida Bay. The Whitewater Bay estuarine system is indirectly coupled with Florida Bay via the Gulf of Mexico and is influenced by water management operations along the Tamiami Trail. Efforts to provide more flow to Taylor Slough and northeastern Florida Bay during dry periods may result in less flow to Shark Slough. Baseline information must be synthesized, monitoring necessities defined and modeling evaluations pursued to determine which resources can best be used to evaluate effects of freshwater flows to Whitewater Bay and western Florida Bay.
- Field tests should be conducted to verify the flow-salinity relationships derived in this report. Especially, controlled releases of water should be provided to Taylor River during the dry season to determine the relationships between the volume of water delivered and the resulting salinity conditions along the transect from the transition zone to Florida Bay.
- Relationships should be further investigated between salinity and gauged water levels and flows at various sites in Florida Bay and in the southern Everglades and C-111 basin. Future analyses should be based on improved hydrologic and hydrodynamic models currently being developed for the FBFKFS or other projects in the region.
- Any future Florida Bay MFL should be should be evaluated to ensure consistency with current Everglades MFL criteria. These criteria are based on stage (water level), so quantitative links need to be established relating Everglades stages to flows and salinity in Florida Bay.
- As new information and improved or new modeling tools become available and structural modifications of the water management system are made within the region, MFL criteria should be reviewed and revised as needed.

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Appendix K-

Overall Review and Responses to Technical Questions to "Technical Documentation to Support Development ofMinimum Flows and Levels (MFL) for Florida Bay"

Peer Review Report

Overall Review and Responses to Technical Questions to "Technical Documentation to Support Development of Minimum Flows and Levels (MFL) for Florida Bay"

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July 2006

I. Overview:

As a large subtropical estuary, rich in unique wildlife, Florida Bay is arguably one of the most important estuaries in the United States. Accordingly, Florida Bay has been identified as a priority water body by the South Florida Water Management District (SFWMD) which manages a significant portion of the freshwater inflow from the adjacent landmass. Estuaries depend on freshwater inputs to maintain a salinity gradient whereby a wide variety of biota can flourish, from seagrass species at the primary producer level to fish and bird species at the higher trophic levels. Unfortunately, hyper-salinity in the central portion of Florida Bay has sometimes been in the range of 50–60 during dry years. The draft document we reviewed describes an approach for establishing Minimum Flows and Levels (MFL) for Florida Bay across the land-sea interface with the Everglades. In order to better protect Florida Bay from excessive hyper-salinity resulting from low inflow of freshwater, the MFL focuses on the Everglades-Florida Bay transition zone in the northeastern portion of the Bay (from the Taylor River through Little Madiera Bay to Eagle Key Basin). The overall management goal is the maintenance of enough freshwater inflow to the Florida Bay estuary to be able to sustain habitat for submersed aquatic vegetation (SAV) in both the transitional freshwater wetlands and adjacent estuarine areas.

After considerable review of resource impacts and modeling output, the staff of the SFWMD has identified *Ruppia maritima* as the key indicator species for the transition zone. The draft document makes the argument that if freshwater inflow is adequate to ensure continued survival of *Ruppia maritima* at the estuarine interface, it will also be adequate to maintain marine seagrass species downstream (including *Halodule wrightii* and *Thalassia testudinum*) in the northeastern portion of the Bay. Because seagrasses occur on nearly 87% of the bottom in Florida Bay (Fourqurean et al. 2002), and because of their demonstrated importance to the abundance, growth and survival of many finfish and shellfish (Heck et al. 2003), the selection or *Ruppia maritima* by the SFWMD as an indicator species appears to be an appropriate candidate for evaluating the impacts of alternative freshwater input scenarios to the Bay.

The scientific review panel concurred that the Northeastern portion of the Bay is indeed the most logical place to set the MFL since this is an area that is most highly influenced by freshwater runoff from the dominant source in the Southern Everglades (i.e. Taylor Slough) and it is also an ideal measurement location where there is adequate historical data enabling managers to gauge changes over time. Although the present

MFL is an important first step, it would be useful to expand the salinity/resource relationships described here in the future to be able to account for additional inflows to the Bay. The proposed minimum flow requirements may be adequate for survival of *Ruppia maritima*, but the environment needs to be monitored thereafter to ensure that this is indeed a good indicator species for the rest of the system from invertebrates through fish. Also, *Ruppia* is one of the more robust species in terms of salinity tolerance and it might be possible to eventually switch to a more sensitive species (e.g. *Utricularia spp*), once the system is more stabilized and more information is available on these species in the transition zone. Of course, there may be numerous other factors, such as increased nutrient loading, the presence of pollutants, invasive species, and hurricanes, which could potentially have adverse effects *on Ruppia maritima* and other SAV (and most likely other components of the ecosystem), so an ecosystem perspective should be maintained.

The panel members generally agreed that the treatment of the ecology of seagrasses is detailed and the modeling of plant growth and competition processes is state of the art. However, there are additional pieces of information and modeling which may be helpful in strengthening the conclusions of this report. Although seagrasses affect many physical and biogeochemical processes, it is their role as essential "nursery habitats" for the juveniles of many economically-important taxa that led to the large amount of funding for research on seagrasses in the past two decades (cf. Duarte 2002). That is, the factors determining the abundance of the economically important seagrass-associated animals, and not the seagasses themselves, are of greatest interest to most citizens. For this reason, in addition to emphasizing Florida Bay seagrass assemblages, another major focus of the SFWMD should be on these animals. Surprisingly, the treatment of how altered freshwater input might affect seagrass-associated animals, termed higher trophic levels (HTL) in the MFL draft document, is much less detailed and rigorous than that given the seagrasses, and relies primarily on correlative information. While overall conclusions would probably not change significantly, additional sampling, experiments and modeling efforts could bolster the HTL portion of the Report. This is an important issue that should be addressed in preparing the final Report and in determining future work carried out by the SFWMD (in conjunction with other groups in South Florida including Everglades National Park and the Audubon Society).

We view the setting of the MFL as an important management tool since it should ensure that low flows do not present unrecoverable stress on Florida Bay. As such, the MFL might be best viewed as a field scale experiment and the inflow goal of 105,000 acre ft per year may have to be altered depending on future ecosystem responses which should be carefully monitored by the SFWMD. The review team is in agreement that an adaptive management approach needs to be taken concerning the MFL and we also agree with the Recommendations for Future Work outlined by the staff (p. 145). A flexible management approach is especially important in estuaries where sea-level rise could not only change shoreline configurations, but also ecosystem dynamics over the next several decades. Although it is not possible to gauge the magnitude of change at present, seaward incursions will undoubtedly occur by the end of the present century and these will have an impact on salinity in the transition zone. If *Ruppia* is to be maintained where it now regularly occurs, the MFL most likely will have to be adjusted upwards.

II. We provide responses to the specific technical questions raised by the District.

General Questions:

1. Does the compiled information, including data modeling tools, and literature review, provide a scientific basis for the conclusions reached?

The overall approach for establishing the MFL goal for Florida Bay is scientifically sound. The District has done a thorough job reviewing a wealth of literature for this document and there are ample supporting materials from literature reviews as well as a suite of models to support the conclusions. The various models and other analyses are fairly well integrated and provide an extensive depiction of the northeastern Florida Bay ecosystem. However, the approach is complex and the MFL document could benefit from generalized flow charts showing both model structures and interrelationships among the various models and analyses used in the development of the MFL. Also the document would be easier to follow if Appendices/supporting documentation were referred to, where appropriate, in the text. Generally, conclusions in the MFL document were well supported by literature, data and/or modeling.

2. Does the analysis identify a relationship between salinity and associated changes or defined valued components and functions of the ecosystem?

The approach taken here looks explicitly at the relationship between salinity and submersed aquatic vegetation (SAV) species (*Ruppia maritima, Halodule wrightii, Thalassia testudinum*), with the assumption that many of the valued components and functions of the ecosystem are dependent on the integrity of these habitats. This is a valid assumption, as numerous studies have shown that SAV is important as food and shelter for the rest of the community, and that they also mediate sediment accumulation, nutrient cycling and other ecosystem processes in estuaries (Kemp et al. 1983). Although the MFL document does provide information regarding the requirements of floral components of the Florida Bay Estuary (*Halodule, Thalassia* and *Syringodium*), more effort needs to be made in the future to better cover the inter-relationships of habitat, salinity and other requirements of the Higher Trophic Levels (various fish and crustaceans in particular). The specifics of the *Ruppia* in the transition zone and the GAM analyses are evaluated in more detail below (in response to question 15).

An intriguing question concerns what changes might take place if *Ruppia* were to disappear from the transition zone during extended periods of drought and/or low freshwater input? For example, would *Halodule* colonize the area formerly occupied by *Ruppia,* and if so how quickly might this happen? If *Halodule* did colonize the former *Ruppia* habitat what would this mean for the animals usually associated with *Ruppia*? Would there be a net change in primary and secondary production or merely a minor shift in the species composition of the dominant plants and animals? Alternatively, might the former *Ruppia* bed be colonized by macroalgae, and if so what would this imply for associated animals? It would be useful to see some explicit predictions of alternative ecosystem-level scenarios that might occur after the loss of *Ruppia* and its associated habitat value under greatly elevated salinities. Plants and animals interact and there is a better need to integrate the faunal work on HTLs with the seagrass efforts to address these plant-animal interactions (see comments on higher trophic levels below in question 15).

3. Does the technical approach identify the duration of salinity variation and associated impacts to valued components and functions of the ecosystem?

The approach does not focus on salinity "variation" *per se*. Rather, it identifies the maximum salinities that have the potential to negatively affect *Ruppia* (and to a lesser extent seagrasses). The primary focus on SAV is justifiable based on the understanding that it provides much of the basic structure to ecological communities in shallow waters and as such is linked to valued ecosystem components (Stevenson 1988), as described in Q 2, above. However, more attention should be directed in the future at determining salinity relationships for HTL organisms using field, mesocosm, and/or modeling studies.

4. Does the analysis identify a frequency of salinity variation that would result in loss of valued functions of the ecosystem that would persist for multiple years?

The report does not identify salinity variation, but rather provides a rationale for choosing the target salinities that would be expected to negatively affect *Ruppia*. The argument is made that the same low flows that would affect *Ruppia* would also adversely affect seagrasses, such that protecting *Ruppia* in the transition zone would concurrently protect downstream areas as well. *Ruppia maritima* is a cosmopolitan species which appears to have different salinity tolerances for seed germination ranging from 15 to 30 to 40 over its geographic range from North Carolina to Florida and southward to Brazil (Koch and Seeliger 1988, Koch and Dawes 1991). Seed germination is especially critical in regrowth after a complete dieback of plants. More specifics of the *Ruppia* and seagrass relationships are evaluated in more detail below in #5.

5. Does the indicator approach used in the document (Ruppia maritima as an indicator of overall conditions of the ecosystem) identify the threshold hydrologic and environmental conditions capable of causing impacts that take more than two years to recover in the transition zone?

Although the MFL document provides a good theoretical basis for choosing *Ruppia* as an indicator, there is also a clear need for more research on this plant coupled with continued monitoring of SAV in Taylor Slough. The document suggests that 30-day average salinities > 30 during two consecutive years would be detrimental to *Ruppia*, and that recovery would take at least 2 years. These are reasonable starting points given the information compiled for the report, but in neither case is there enough information in hand to make these statements with utmost certainty based again on the plasticity of various ecotypes of *Ruppia maritima* which have been well documented for more than a quarter century by Verhoeven (1979).

The use of correlative data, along with some recent as yet unpublished experimental data on the effects of salinity on *Ruppia* in the transition zone, to define the effects of alternative freshwater input scenarios to the transition zone of Florida Bay was clearly and logically developed, even though there are a number of questions that have not been completely answered. Some of these were noted by the Report's authors. Given the paucity of published experiments on the effects of various physico-chemical factors on *R. maritima*, data gaps still exist and it would be desirable to identify them and initiate efforts to plug them. Studies that could fill these gaps include multi-factorial experiments to evaluate the single and interactive effects of varying salinity, nutrient loading and light levels on *R. maritima* survival and growth. Such experiments are important, since changes in salinity are likely to be accompanied by changes in nutrient regime and light levels. In addition, bioassays of the effects of co-variation in all these variables on seed production and seed banks would be valuable. Thus, the correlative approach taken to evaluate the effects of salinity should be supplemented by studies designed to clarify the role of important physico-chemical variables and how they may interact with salinity.

Generally, studies to date support the conclusion that seed germination is inhibited at salinities > 30, which is consistent with literature observations. This is reinforced by the observations of the Audubon monitoring program that *Ruppia* is virtually absent when 30-day average salinities exceed 30. However, the adult plants can withstand far higher salinities for longer periods of time, so it would be useful to continue monitoring plant response to salinity, and also to develop a better understanding of the conditions (and timing) necessary for reproductive success. Recovery after 2 years is suggested based on the Audubon observations and literature reports, but again it is critical to continue monitoring to document the time-frame for recovery from the current decline, and it would be useful to have more detail regarding the salinities and the time-frame for recovery associated with the observations of Montague et al. (1989).

6. *Does the indicator approach in the transition zone identify the threshold hydrologic and environmental conditions capable of causing impacts that take more than two years to recover in northeastern Florida Bay?*

Once the *Ruppia*/salinity relationships have been finalized (see Q 5 and Q 8), identifying the appropriate flow conditions to maintain these salinities becomes a matter of relating salinity to inflow (Q 13). The analysis of flows also supports the notion that maintaining salinities < 30 in the transition zone would prevent the northeastern portion of the Bay from becoming hypersaline (> 40), which would thus provide appropriate conditions for seagrasses (*Thalassia* and *Halodule*). Thus flourishing *Ruppia* in the transition area should provide a key indicator that the downstream areas of Florida Bay do not suffer from excessive hypersalinity.

Data sufficiency:

7. Do the water budget element including rainfall, Evapo-transpiration (E-T), surface water level and flow data) described in the report provide a basis upon which to identify relationships between freshwater inflow and salinity conditions in the bay?

The water budget is appropriate for identifying the relationships between inflow and salinity, but it is incumbent upon the District to revise the current document so that the budget is clearly and consistently described. The staff response to the questions we raised during our initial review (3/27/06) helps to clarify some of this. One outstanding issue has to do with the ET estimate used for this report. The staff response to Dr Alber's question indicates that the MFL base case ET estimate was used, yet the document refers to a different estimate (53% of total solar radiation).

8. Does the information support the report's conclusions regarding the relationship between salinity and the associated changes to defined valued components and functions of the ecosystem?

Salinity is often a controlling variable in estuaries, and the report provides relevant information describing the salinity response of many key components of both the transition zone and NE Florida Bay ecosystems. However, given the focus on *Ruppia* it would be useful to determine if it can be explicitly linked to other components of the ecosystem – for example, the District should compare *Ruppia* cover with Audubon data regarding the abundance of roseate spoonbills and other birds.

9. Are the literature survey, laboratory and field studies sufficient to determine relationships between salinity and the indicator species Ruppia?

Although *Ruppia* has been well studied in regard to salinity responses, there is quite a range of reported tolerance depending on location (Koch and Dawes 1991). In addition, as described in answer to (Q 5), additional analysis of *Ruppia* is warranted. Before the MFL is finalized, we would strongly recommend re-visiting the data used to compare salinity with *Ruppia* cover (Figs. 34 and 35 of the MFL document) to determine:

- whether a logistic fit would be better than a linear relationship
- whether a different salinity-averaging period improves these relationships

Along these lines, it might be appropriate to compare *Ruppia* cover with the salinity at the time the plant germinated, particularly given the difference in tolerance between the adult plants and germination conditions. Alternatively, the average growing season salinity, or possibly the maximum salinity the plant experienced might be useful to evaluate, as any of these might be more relevant than 30-day averages.

- whether the 2000-2001 period of low *Ruppia* cover did in fact correspond to average monthly salinities > 30 or if this represents a time when *Ruppia* cover diminished as a consequence of something other than salinity (i.e. a false positive). As part of this, we would recommend incorporating the figure that shows *Ruppia* cover over time (which was shown at the public meeting on 3/29/06) and presenting it alongside continuous salinity information (i.e. as opposed to the discrete samples that were used to generate the graph presented at the meeting).

All of this analysis, as well as continued monitoring, will help determine when the critical period might be for *Ruppia* response to salinity, as well as the time-frame for recovery.

10. Do the literature survey, laboratory and field studies support the proposal that Ruppia/salinity relationships is an indicator of valued components and functions of the Florida Bay ecosystem?

The information provided could be improved (see Q 5, Q 8, Q 9), but it does support the relationship between *Ruppia* and salinity. The report also makes the case that salinities/flows that are protective of *Ruppia* will be sufficient for downstream seagrasses, but it would be beneficial to strengthen this linkage (see Q 13). The document identifies the habitat value of *Ruppia* and other SAV in the transition zone as a data gap, and this should be a high priority for future work.

Modeling:

11. Are the hydrologic and ecological models used in this study appropriate for this application? Are these models sufficiently supported by monitoring and research data (e.g. for calibration and validation) such that they yield credible evaluations tools for this application?

There are numerous models used in this analysis: two hydrologic models, a seagrass model, and a GAM analysis of higher trophic levels. These are each considered further in the questions below, but the relationships between inflow and salinity in both the transition zone and the Bay itself are appropriate for this application.

One obvious omission in the modeling efforts involves *Ruppia.* Unfortunately there was no attempt in the MFL document to match the large and commendable effort devoted to modeling the response of *Halodule* and *Thalassia* to changing environmental conditions. Perhaps *Ruppia* could be the focus of subsequent modeling efforts, but the disparity between the allocation of effort devoted to *Ruppia* versus the other two species was puzzling to the review team. The need for a modeling effort on *Ruppia* was noted by the MFL authors themselves and could strengthen the credibility of this evaluation in future years.

12. Does the 33-year hindcasting method support reasonable scientific conclusions regarding the Bay's salinity under current dry conditions in the watershed?

This approach is reasonable. Both the multiple linear regression and FATHOM models performed well under current conditions, and hindcasting was a matter of using historic information regarding inflow and rainfall. When hindcasting, the assumption is made that the current conditions such as the relative amount of inflow through different streams and bay hydrology were stable throughout the period of interest. This is probably not the case, but it is also not likely to be as important in driving salinity patterns as total inflow. Also, (although there are data limitations) there may be some value in going further back in time for additional insight into system responses.

13. Are the hydrologic models sensitive to inflows of surface water such that confidence can be placed in the location, extent and duration of the resulting salinity predictions?

There are two hydrologic models here, both of which performed fairly well. The correlation analysis relates flow at USGS gages (and elevation in the Everglades) to salinity in the transition zone, and is a fairly good predictor of observed data. The FATHOM model is adequate in Little Madiera and Eagle Key basins, although it does better in some of the other basins. It is not entirely clear why the decision was made to work with the base case if some of the alternative estimates explored in the FATHOM report would have improved the model performance for the basins in question. If it is not a large difference, this needs to be stated and quantified. If it is a large difference, then the decision should be justified. It would also be instructive to include more information regarding the relationship between the predictions made by the two methods. The information Dr. Frank Marshall presented at the public meeting (3/29/06) suggested that there was fairly good agreement between the two methods, and that should be included in the report as a way to justify comparing predicted salinities in the transition zone with those in the Bay. In addition, it will be important to revisit these predictions in the context of CERP as other efforts (i.e. FBFKFS) move forward with improved modeling.

14. Does the hydrologic and SAV modeling in northeastern Florida Bay (for Halodule and Thalassia) support the linkage between salinity conditions in the transition zone and the impacts in northeastern Florida Bay?

The hydrologic model has been discussed above (Q 12, Q 13). The SAV model output suggests that *Halodule* declines when exposed to increased salinities, although the response varies from basin to basin (Fig. 46). This is difficult to infer from the literature, as both *Halodule* and *Thalassia* have broad salinity tolerances and field observations (Fig. 40) show virtually no relationship between shoot density and salinities up to 40. It would be useful to sort the data presented in Fig. 40 by basin and compare these with model predictions for those same areas (this appears to be a separate data set than that used for model calibration). This analysis is important to pursue as a way to understand the relative importance of salinity in determining SAV patterns. It may be that salinity is not the variable driving the differential response in these basins, but rather differences in the plants' response to light, sulfide concentrations, or other factors, and the model provides a way to help understand these interactions. As we understand it, however, the goal of the MFL is not necessarily to provide everything that the plants need to thrive but rather to ensure that they are not harmed by low flow conditions. The report would also benefit from a better description of model structure, much of which is now contained in Appendix I. As part of this, it would be useful to include a better description of how shading and competition were handled.

15. Does the upper trophic level modeling support the linkage between conditions in the transition zone and ecological impacts in northeastern Florida Bay?

Generally, there are three overarching issues relating to seagrasses and higher trophic levels (HTLs) and these have relevance to the modeling efforts. The first is the important role that epiphyte grazers play in controlling the abundance of algae on the leaves of seagrasses. Much work on the effects of nutrients on seagrasses has focused on nutrient loading and how this could stimulate algae to overgrow seagrasses, along with other variables such as light and salinity. Indeed, the conceptual Florida Bay model leans heavily toward a bottom-up view of seagrass meadows (Rudnick et al. 2004), as do the seagrass modeling efforts discussed above. However, a recent meta-analysis by Hughes et al. (2004) evaluated the relative effects of nutrients and grazers in controlling algal abundance on seagrass leaves. Hughes et al. (2004) concluded that both were important, but in studies that concurrently evaluated the relative importance of both factors, grazers explained more of the variance in algal biomass than did nutrients. Therefore, it would be useful to incorporate the effect of grazers in the future updates of the *Halodule* and *Thalassia* models.

The second is that many animals use multiple habitats at various times during their life. For example, organisms may shelter in seagrass beds but forage in adjacent unvegetated substrates, or they may move back and forth between seagrass and mangrove habitats. In fact, migration among adjacent habitats is a characteristic of the life history of several of the most common fishes in Florida Bay (e.g., gray snapper, cf. Nagelkerken et al. 2002 and references therein), and the issue of habitat connectivity is important, yet thus far uninvestigated in the present modeling efforts. The central issue here is that without all habitats available, many species will not thrive, and food webs may be structured very differently depending on the availability of multiple habitats to species with complex life cycles (Valentine and Heck 2005). This raises the question of whether changes in other habitats, such as mangrove swamps, for example, might negatively affect animal species thought to be characteristic of *Ruppia* beds, but who may also rely on habitats adjacent to *Ruppia* meadows. This possibility deserves consideration in future HTL assessments.

The third is the direct and indirect effects that harvesting of fishes and other large animals may have had on south Florida ecosystems. Many taxa of snappers, groupers and other families of fishes are heavily fished in south Florida (Bohnsack et al. 1994). It is difficult to know how current densities of targeted fishes relate to historical abundances, and whether ecosystems function in ways that are similar or very different than they did before extensive fishing pressures existed. But there is reason to believe that fishing may have produced large changes in trophic relationships and habitats in Florida Bay (Jackson et al. 2001) and this topic deserves more consideration in the MFL document. In addition, it could be relevant to changing levels of seagrass consumption if waterfowl, manatees, green turtles or other grazers (e.g., sea urchins) were to increase in abundance, as well as to cascading trophic effects that could affect the entire food web structure if abundance of of higher order consumers were to change.

In general, the treatment of higher trophic levels in the draft MFL document was much less fully developed than that of the seagrasses. The nearly complete reliance on correlational (GAMS) analysis is somewhat surprising given the long history of the concerns about higher trophic levels in Florida Bay. One often looks for correlations in data sets to help formulate hypotheses that are later tested by rigorously designed experiments. In the case of higher trophic levels of Florida Bay, it does not appear that analysis has advanced very far from searching for significant correlations between selected animal abundances, physico-chemical factors and estimates of seagrass abundance to process-related research. Unfortunately, after a large effort to calculate such correlations, their magnitude was often quite low, and only modest amounts of variance (low r^2 values) in the dependent variables (animal abundance) could be explained by the independent variables investigated. For example, models were considered to be "adequate" when r^2 was greater than or equal to 0.1 and p was less than or equal to 0.1. This means that 90% of the variance in the abundance of the Higher Trophic Level species being considered could remain unexplained by the model and still be considered "adequate" (along with a very high p-value of 0.1). In most cases the amount of variance explained was between 10 and 40%, and the most important independent variables in the throw trap data set were: Julian date, habitat, *Halodule* standing crop, depth and salinity, while for the trawl data the most important variables were: region, *Syringodium*, depth, salinity and *Thalassia* and *Halodule*. The fact that Julian date and region were the best predictors in the throw trap and trawl data, respectively, does not inspire confidence in the ability of the models to be of great use in predicting faunal responses to changing salinity regimes.

Unfortunately the Higher Trophic Level modeling did not include dissolved oxygen levels as an independent variable, an omission that is puzzling in such a shallow, warm and organically rich bank and basin system like FB. Perhaps more surprisingly, the HTL statistical modeling did not include an assessment of the effects of *Ruppia*, the indicator species chosen as the focus of the Report, on the HTL species chosen for study. Indeed, it does not appear that HTL species living in the *Ruppia* habitat were sampled by any of the HTL sampling programs. This suggests a lack of coordination between the HTL investigators and the other investigators whose work appears in the Report.

The need to improve the rigor and scope of the HTL studies in Florida Bay has been commented on previously (Boesch et al. 1997; Deegan et al. 1998; Hobbie et al. 2001). Issues noted herein have been discussed in the references cited above, and include: an incomplete assessment of the habitat value of individual seagrass species, as well as macroalgae, for the larger species of fishes and crustaceans; and a similarly incomplete assessment of how changes in the relative abundance of seagrasses could affect these species. The best way to address these questions is a combination of laboratory (mesocosms) and field experimentation and this was recommended previously (Boesch et al. 1997; Deegan et al. 1998). Additional factors deserving of consideration include: how variation in infaunal and epifaunal benthic taxa, the food of most fish and crustacean taxa considered by the HTL investigators, might influence their abundance; the previously mentioned effects of epiphytic grazing species of invertebrates and fishes; a more detailed consideration of the effects of harvesting on Higher Trophic Levels and the potential for cascading trophic effects; and further investigation of interactions between filter feeding sponges, water clarity and seagrass abundance and species composition.

The reliance on correlative approaches, which were not able to explain much of the variance in the abundance of the Higher Trophic Level species selected for study, and the absence of carefully designed and executed experiments, diminishes the strength of the conclusions that can be drawn and the confidence that can be placed in predictions about the effects of altered freshwater inputs. More effort should be made to use studies (even if unpublished) on the relationships between *Ruppia* and higher trophic levels, to fill critical data gaps noted here, would strengthen the Higher Trophic Level section of the MFL document significantly.

Conceptually, linking predictions of salinity and seagrass from the FATHOM and SAV models with upper trophic level response is an attractive idea. However, this should only be used in cases where these variables (salinity, seagrass cover) were found to be important predictors of upper trophic levels in the GAM analyses. In many of the cases considered here, salinity (or seagrasses) only accounted for a small proportion of the observed variability in upper trophic level biomass, which makes this approach less informative. Moreover, *Syringodium* and/or depth were often important variables in the GAM models, and these were not considered. Although there is evidence that salinity has an effect on all of these organisms, the GAM analyses indicate that it is not necessarily the controlling factor in their distribution (at least at the salinities associated with these sets of observations). Rather than work on predicting upper trophic level response to various scenarios, a more reasonable goal for the MFL analysis might be to determine what salinities would cause them harm, either directly via their physiological response or indirectly through loss of food and habitat, and then work to ensure that salinities do not reach these levels. Mesocosms are often ideal tools to approach these type of physio-ecological issues whereby critical feedback loops found in natural communities can be elucidated.

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