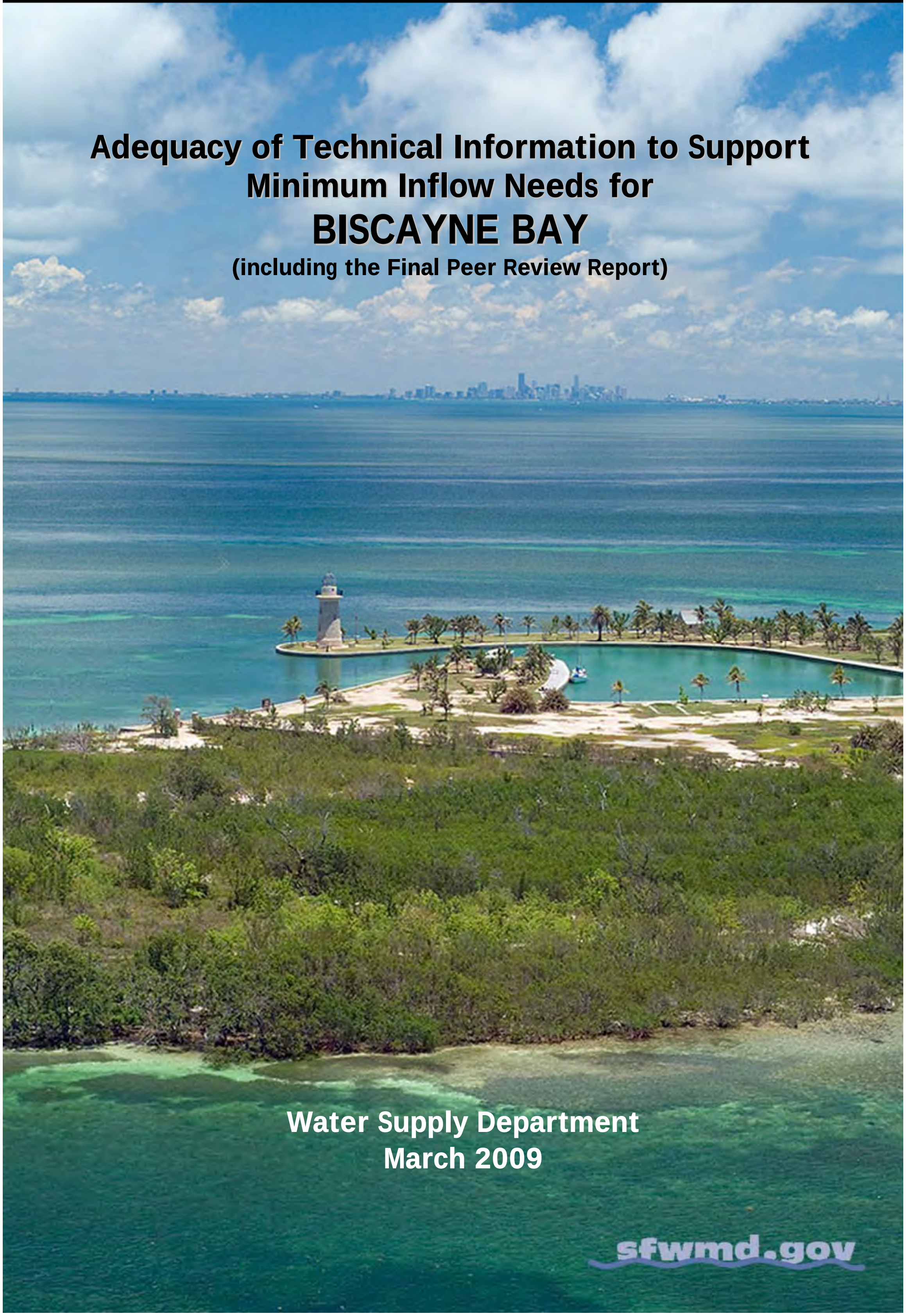
SOUTH FLORIDA WATER MANAGEMENT DISTRICT



Adequacy of Technical Information to Support Minimum Inflow Needs for
BISCAYNE BAY
(including the Final Peer Review Report)

Water Supply Department
March 2009

sfwmd.gov

Preface

The District convened an external scientific peer review panel to review and provide comment on the draft technical report entitled, *Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay* (October 2008). Ten questions, upon which the peer review was to be based, were presented to the panel. A public workshop held on October 28, 2008 was an integral part of the review, in which the panel began assembling their responses and the public was given the opportunity to provide comments. The panel addressed each of the 10 questions in their final report of November 13, 2008 (Montagna *et al*. 2008), which is included as Appendix L of this document. This final technical document also includes editorial corrections and enhancements identified by the peer review panel as part of Question 1 and Appendix 1 of their final report. Revisions were made to eliminate the redundancy noted in Chapters 1 and 4, clarify and improve several figures and tables, complete citations and provide consistent reference style, and address other minor editorial corrections.

Acknowledgements

The South Florida Water Management District gratefully acknowledges the contributions of many professionals who made the following report possible.

The following managers who supported this effort are recognized:

Carol Wehle, *Executive Director*

Chip Merriam, *Deputy Executive Director, Water Resources*

Marjorie Craig, *Director, Water Supply Department*

John Mulliken, *Director, Water Supply Planning Division*

In particular, the following contributors are acknowledged and appreciated:

Technical Lead
Melody Hunt

Principal Authors
Melody Hunt
John Maxted

Supporting Contributors
Rick Alleman
Miguel Diaz
Jason Godin
John Janzen
Steve Krupa
David Swift

Technical Editing
Dawn Rose

Coordination of Peer Review
Jason Godin
John Maxted

Legal Support
Beth Lewis

Water Policy Support
Scott Burns

Contract Support
Environmental Consulting and Technology, Inc.

Executive Summary

The South Florida Water Management District (SFWMD or District) examined the adequacy of available technical information to support the minimum inflow needs for Biscayne Bay. This peer review was conducted in advance of rule development due to the complexity of the relationships between freshwater inflow, salinity, and protection of the bay's biological resources (**Figure 1**).

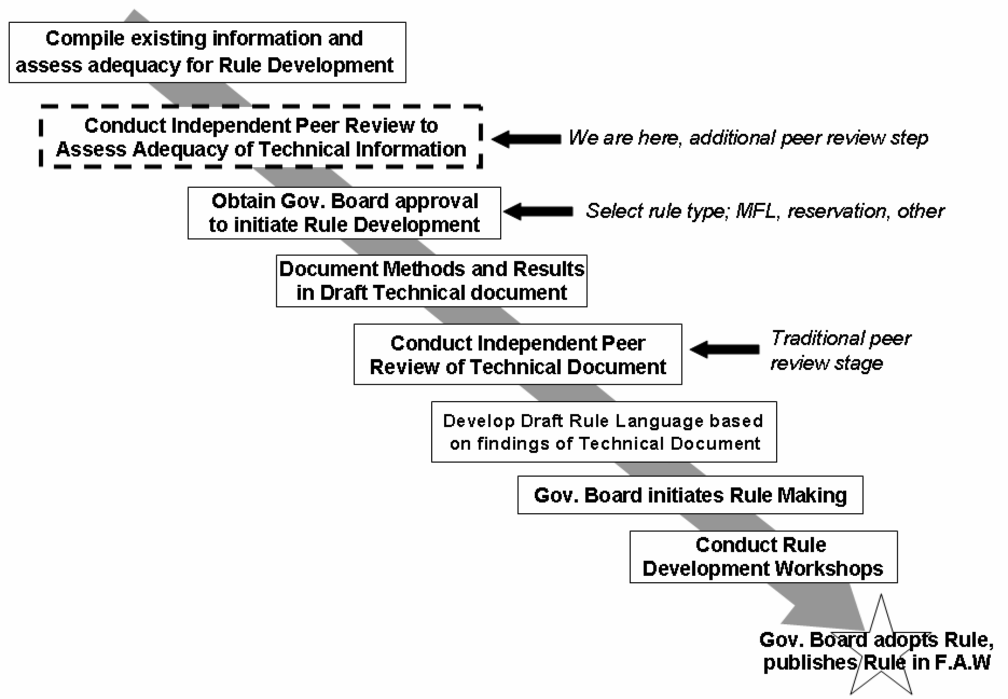


Figure 1. Proposed steps to develop inflow criteria for Biscayne Bay, including the rule development process. (Source: SFWMD 2008)

Several regulatory tools can be used to develop inflow criteria for coastal systems in Florida – the primary options being minimum flows and levels, water reservations, and water availability-type rules. This report serves as a broad-scale assessment of Biscayne Bay and the associated watershed and does not provide technical analysis to support a specific regulatory tool.

Modifications to natural flow patterns have been made in the Biscayne Bay watershed to accommodate growth and control flooding. These changes have affected the volume and timing of fresh water discharged to the bay. Biscayne Bay has experienced considerable change due to a century of extensive regional population growth and considerable coastal watershed development. Further complicating the analyses, there is limited information and experience to draw upon in developing inflow criteria for wetland/lagoonal coastal systems that have widely distributed inflows such as Biscayne Bay. All estuarine minimum inflow criteria developed by the SFWMD to date have been established for ecosystems with a defined low salinity reach or freshwater floodplain, where a freshwater dominant valued ecosystem component or an indicator species exists that is sensitive to salinity intrusion. In contrast, the western advance of saltwater intrusion occurring in the groundwater within the watershed, combined with the channelization of surface flows by canals, have altered the estuarine zone of western Biscayne Bay. Currently, instead of a wetland/tidal creek estuarine area, a relatively small and highly variable estuarine gradient exists in nearshore areas of the bay near canal inflows points, which are dominated by communities and organisms that can tolerate a wide range of salinity conditions.

The following four assumptions are made in this report. First, the analysis assumes existing conditions regarding population, land use, and infrastructure. Empirical and modeled data were used to characterize freshwater flows and salinities in the bay over a 36-year period of record that reflects a range of climatic conditions. Second, the study area encompasses the entire Biscayne Bay system from the Oleta River (north) to the Barnes Sound (south) because the freshwater sources within these basins cover this broad area and the bay's ecological compartments are interconnected. Results are provided for the North, Central, and South regions of the bay and eight subareas. Third, this report is focused on flow and salinity; other water quality parameters (e.g., nutrients) are only briefly discussed. Fourth, the analysis is directed primarily to low flow conditions when elevated salinities may be an issue.

Three primary methods are typically used by the District to determine freshwater inflow criteria for estuarine systems: freshwater inflow-based, estuarine condition-based, and estuarine resource-based. Regardless of the approach used, technical evaluations must establish the link between freshwater inflow, condition (i.e., salinity), and the response of estuarine resources. The specific method selected determines the context and evaluations that are performed to establish the links. All estuarine inflow criteria adopted thus far by the SFWMD use freshwater valued ecosystem components or indicator species linked with a defined salinity threshold. Significant harm, a term used to define an exceedance of a minimum flow or level, is established when salinity exceeds the threshold and the valued ecosystem component or indicator species takes more than two years to recover. Due to a combination of the diffuse and modified inflow characteristics of Biscayne Bay's nearshore estuarine zone, it is difficult to apply a resource-based approach that links flow or salinity to a freshwater valued ecosystem component with a salinity threshold.

This document contains four chapters: Chapter 1: Introduction; Chapter 2: Hydrology; Chapter 3: Biological Resources; and Chapter 4: Potential Approaches for Developing Inflow Criteria. Chapter 1 provides an overview of available options and criteria associated with the different options. Chapter 2 provides an overview of hydrologic components and the history of changes in the watershed. Hydrologic evaluations include a system-wide water budget and an analysis of long-term salinity patterns in the bay. The analysis uses salinity as the physical link between freshwater inflows and biological resources. Chapter 3 surveys the habitats and organisms found within Biscayne Bay and evaluates the salinity sensitivity of a potential valued ecosystem component candidate species or community, in the context of minimum inflows. Chapter 4 presents an overview of the potential approaches for inflow development and summarizes inflow evaluations made for Biscayne Bay and their associated application. Additional approaches that have not been previously considered are also presented.

HYDROLOGY

An important aspect of inflow evaluation is to establish the link between inflows, stage or levels, and salinity. An understanding of the hydrology is essential to establish such links, including the review of physical characteristics of the watershed and development of a water budget to quantify existing inflows. A whole system approach, encompassing all of Biscayne Bay, was used to characterize the hydrology under existing conditions.

An integrated canal network leading into Biscayne Bay, primarily designed and operated for flood control through the regulation of canal levels, supplies canal inflows through 14 major coastal structures. Unlike a riverine system containing one major inflow source, these numerous inflows are distributed along Biscayne Bay's 50-miles of coastal shoreline. Overland surface water and groundwater are also important inflow sources. Historically, the southern Everglades, Biscayne Bay, and Florida Bay were part of a larger hydrologically connected system of wetlands, tidal creeks, and coastal lagoons underlain by the highly transmissive Biscayne aquifer. During the past century, the hydrology of the Biscayne Bay watershed has been highly modified for agricultural, urban, and commercial development. A landward coastal transition zone no longer exits to direct surface inflow into the bay through natural wetlands and tidal creeks that would allow a well-defined and stable salinity gradient within these habitats. The inland movement of the freshwater/saltwater interface is a major concern in the coastal areas of Miami-Dade County.

Within the three broad regions of Biscayne Bay – North, Central, and South, hydrologic analyses of existing conditions are provided for eight geographic subareas of those regions: Snake Creek/Oleta River, North, and Miami River subareas of the North region; North Central, South Central Inshore, and South Central Mid-bay subareas of the Central region; and Card Sound and Barnes Sound subareas of the South region. A simple mass balance model was developed to characterize the entire system using existing conditions with regard to population, land use, consumptive use, canal flows, groundwater flows, and water management operations. The model was used to show salinity conditions in the bay and construct a water budget that represents the 36-year period of record.

The water budget illustrates the different inflow characteristics for each of the three regions. The North region is dominated by canal inflow and receives the highest quantity of total inflow. This region has a low freshwater displacement, thus, the freshwater does not remain in the system and is replaced with marine water in a relatively short time. In contrast, the total inflow in the South region is low relative to the other regions and is dominated by a combination of ungauged surface inflow and groundwater. This region has a high freshwater displacement, and thus, freshwater that enters the system remains for a relatively long time compared with the North. However, the low inflow allows the potential for hypersaline conditions during drier periods. The Central region is dominated by a combination of groundwater and canal inflow and has an intermediate freshwater displacement characterized by highly variable salinities near canals.

Salinity observations and model results show the differences between regions that are reflective of the inflow characteristics and physiographic differences. Hypersalinity, or salinity that exceeds normal expected marine conditions, occurs particularly in dry years in all regions. Additional analyses were conducted to identify which regions were sensitive or linked to freshwater inputs under high salinity and low salinity conditions. The analyses show that all areas of the bay are sensitive to inflow quantity, but the relative influence of canal and groundwater inflows is different in each region. From an overall perspective, the system is most sensitive to groundwater inputs under conditions resulting in high salinity (i.e., low flow). Under conditions resulting in low salinity (i.e., high inflow), the system is most sensitive to canal inflow. When the inflow sources are considered individually, there are six subareas (distributed throughout all regions of the bay) in which annual maximum salinity is sensitive to annual groundwater inflow; two subareas that are sensitive to wetland or ungauged surface flow (Central inshore and Mid-bay); and one subarea that is sensitive to canal flow (North).

BIOLOGICAL RESOURCES

When considering specific inflow criteria, it is important to describe the biota and habitats and link the effects of salinity conditions to the protection, or survival of the biota. The linkage and thus the context of the evaluations are specific to the type of regulatory tool being considered. The resources and biota are described in general terms; however, this section primarily examines the links associated with threshold salinities needed for survival of candidate biota consistent with minimum flow and level criteria because previous evaluations have been conducted in this context.

The North, Central, and South regions of the bay are considered separately due to major differences between inflow sources and land use characteristics. For a decade or more, fish sampling, water quality, and seagrass monitoring have been conducted within the bay, although not all parts of the bay have received the same sampling effort. All three regions of Biscayne Bay support communities of seagrasses and fish, turtles, marine mammals, and birds. The major habitats and biological resources within the Biscayne Bay watershed are wetlands, mangroves, seagrass meadows, and benthic faunal communities. Habitat connections between the coastal and marine ecosystems are apparent. Most of the North region is sea-walled and thus lacks a natural transition zone or mangrove fringe. The shoreline of the Central and South regions is largely undeveloped and bordered by a mangrove fringe. Many of the same species of fish, including juvenile reef fish, which use the mangrove areas in the Central region, also use the South region. Review of freshwater requirements for endangered, threatened, or species of special concern suggest that the American crocodile, the roseate bill spoonbill, and the Florida manatee could be affected by reduction in freshwater flow. However, direct links to salinity thresholds or minimum inflow quantity have not been established. Similarly, survival thresholds linked to a specific salinity that could be used to develop a resource-based approach were not found for other biota or communities.

The fish community in Biscayne Bay has been studied and characterized over the past decade. While no specific salinity thresholds were found, community level patterns were apparent for fish that inhabit nearshore mangrove and seagrass areas in Biscayne Bay. Recent field investigations of fish within Biscayne Bay provide evidence supporting different species under estuarine conditions (i.e., salinities lower than marine) as compared with marine conditions. Additionally, these analyses showed that fish abundance and diversity decreased as the salinity exceeded marine conditions (hypersalinity).

POTENTIAL INFLOW CRITERIA APPROACHES

The development of a practical and scientifically defensible approach on which to base inflow criteria for Biscayne Bay is a challenging task. Chapter 4 presents potential approaches for development of inflow criteria for Biscayne Bay. A substantial amount of evaluation has been conducted in the context of minimum flows and levels for Biscayne Bay and the information referenced in this chapter is primarily within this context. Additional analyses will be required to define specific criteria under any of the potential approaches discussed in this report.

The many unique attributes of Biscayne Bay make this system difficult to evaluate with established methods. The lack of an existing landward estuarine gradient in Biscayne Bay upon which to identify salt sensitive freshwater species makes the evaluation of minimum inflow criteria complex. Reports prepared for the SFWMD by independent contractors summarize and evaluate the use of potential biological resource candidates within specified subareas as defined in the context of minimum flow and levels. Despite considerable efforts, none of the recommendations identifies a salinity threshold or length of exposure to a specific salinity that could be used for a resource-based approach for development of inflow criteria. The reports conclude that a significant amount of supplemental information would be required before inflow criteria could be established.

Generally, less defined links between biota and salinity condition may be possible with a condition-based approach. Although many organisms within the bay ecosystem could tolerate periodic exposure to hypersaline conditions, estuarine function (i.e., functions or communities requiring reduced salinity) in the same area would be lost or greatly reduced. Protection of this estuarine function may be justified in this context. The fish community has been characterized and studied in Biscayne Bay over the past decade with several recent evaluations establishing a link between salinity and the fish community. This avenue may be useful in establishing a condition-based approach, depending on the specific type of inflow criteria considered. The occurrence of hypersalinity is a condition that could be further considered in this context, as estuarine function would be lost for a period of time when these conditions occur.

To develop inflow criteria based on a condition-based approach using an estuarine-function/hypersalinity metric for Biscayne Bay, three key actions are necessary and would require further consideration and evaluation: 1) define hypersalinity, or the "salinity condition," 2) establish the timing, frequency, and duration of the condition with respect to the specific criteria being evaluated, and 3) establish the location and distribution of both salinity and inflow measurements. The link between inflow, stage, or level and salinity would also need to be demonstrated at specific measurement locations for monitoring purposes. This would likely involve additional analyses in targeted areas.

Table of Contents

List of Figures

List of Tables

List of Appendices

Appendix A: Environmental Consulting and Technology, Inc. (ECT) Reports, January 2008 and September 2008 Update (ECT Reports)

ECT. 2008. *Biscayne Bay Freshwater Budget and the Relationship of Inflow to Salinity*. Final Report. Prepared by Environmental Consulting and Technology, Inc.

ECT. 2008. *Biscayne Bay Freshwater Budget and the Relationship of Inflow to Salinity*. Update to Final Report. Prepared by Environmental Consulting and Technology, Inc.

Appendix B: U.S. Department of Interior (USDOI) Reports, 2006 and 2008 (USDOI Reports)

USDOI. 2006. *Ecological Targets for Western Biscayne Bay*. U.S. Department of the Interior.

USDOI. 2008. *Estimates of Flows to Meet Salinity Targets for Western Biscayne Bay*. U.S. Department of the Interior.

Appendix C: Salinity Observations

Appendix D: Barnes, Ferland and Associates, Inc. (BFA) *et al.,* 2004a (BFA Reports)

BFA et al. 2004a. *Freshwater Flow and Ecological Relationships in Biscayne Bay*. Prepared by Barnes, Ferland and Associates, Inc. in association with Lewis Environmental Services, Inc.

Appendix E: Lewis Environmental Services, Inc. Report, 2007 (Lewis Environmental Report)

Lewis Environmental. 2007. *Literature Review of the Effects of Salinity Levels and Variations on Biscayne Bay Biological Resources*. Final Report.

Appendix F: Summary of Biscayne Bay Coastal Wetlands Investigations 2004-2007

Appendix G: Serafy *et al.* Report, 2008 (Serafy Report)

Serafy, J. et al. 2008. *Development of Habitat Suitability Models for Biscayne Bay* Area Fishes: Assessing Salinity Affinity from Abundance Data. Final Report.

Appendix H: Example Analyses to Link Salinity with Inflow and/or Water Level

Appendix I: Description of Miami-Dade County Drainage Basins

Appendix J: Conceptual Ecological Models

Appendix K: SFWMD, Florida Bay Minimum Flow and Level Technical Document, 2006 (Florida Bay MFL Document)

SFWMD. 2006. *Technical Documentation to Support Development of Minimum Flows for Florida Bay*. South Florida Water Management District.

Appendix L: Peer Review Final Report, 2008 (Peer Review Report)

Montagna, P.A. et al. 2008. *Peer Review: Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay*.

Acronyms & Abbreviations

°C or C	degrees in Centigrade
ac-ft	acre-feet
AOML	Atlantic Oceanographic and Meterological Laboratory
BFA	Barnes, Ferland and Associates, Inc.
C&SF Project	Central and Southern Florida Flood Control Project
cfs	cubic feet per second
cm	centimeter
CUP	consumptive use permitting
DERM	Department of Environmental Resource Management
District	South Florida Water Management District
E	Endangered
ECT	Environmental Consulting and Technology, Inc.
ET	evapotranspiration
F.A.C.	Florida Administrative Code
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
FPL	Florida Power & Light
F.S.	Florida Statutes
FWC	Florida Fish and Wildlife Conservation Commission
ha	hectare
km	kilometers
LFA	Lower Floridan aquifer
MFL	minimum flow and level
NCDC	National Climatic Data Center
NGVD	National Geodetic Vertical Datum of 1929
NMFS	National Marine Fisheries Service
NOAA	National Ocean and Atmospheric Administration
NOS	National Ocean Service

ppt	parts per thousand
psu	practical salinity unit
SAS	surficial aquifer system
SAV	submerged aquatic vegetation
SDCS	South Dade Conveyance System
SEAWAT	fully coupled or uncoupled density-dependent flow and transport model
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
sp.	specie
SSC	species of special concern
T	Threatened
TAB-MDS	USACE's multidimensional hydrodynamic model
UFA	Upper Floridan aquifer
U.S.	United States
USACE	United States Army Corps of Engineers
USDOI	United States Department of Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VEC	valued ecosystem component

1

Introduction

PURPOSE AND SCOPE

The purpose of this technical document is to provide a summary of relevant technical information and potential approaches being considered by the South Florida Water Management District (SFWMD or District) to define relationships between freshwater inflows, salinity, and resources in Biscayne Bay. This is a necessary step prior to assessing inflow needs because (a) extensive development and hydrologic alterations have occurred in the Biscayne Bay watershed in the past century, and (b) the technical complexity of the relationships between inflow, salinity, and resources in this large and diverse ecosystem. This report is intended to present a broad-scale assessment that encompasses the entire bay, with detailed reports referenced throughout. Key documents are provided in the Appendices.

Chapter 1 provides a general background about existing inflow criteria, definitions of terms, and water resource protection options. **Chapter 2** provides a description of Biscayne Bay and its watershed and summarizes the existing system and hydrology. Hydrologic analyses are presented, including water budget estimations and salinity patterns for the entire system. **Chapter 3** provides an overview of the habitats and biological resources present within Biscayne Bay. Salinity sensitivity of the resources in the context of low flow conditions and important ecological links are discussed. **Chapter 4** reviews potential approaches for application of existing technical information in the development of inflow criteria, drawing upon existing literature about potential relationships between freshwater flow, salinity, and biological resources. Resource-based approaches used to define appropriate inflows in other coastal ecosystems are summarized, as well as other potential options.

Two primary components of the information are presented. First, conditions over the entire bay are assessed, including the areas of Oleta River, Snake Creek, and Miami River in the northern portion of Biscayne Bay; Biscayne National Park in the central portion; and Card and Barnes sounds in the southern part of the bay. Second, for this evaluation, the freshwater inflow needs of the bay are based on existing land use, surface water operations and facilities, current sea level, and rainfall patterns. A mass balance modeling approach is used to characterize monthly and year-to-year variations in flows and salinities over a 36-year period of record (1965–2000) assuming existing infrastructure. Salinity is the key characteristic considered as it may be linked with both flow and biological resources. This is similar to previous coastal inflow criteria established in south Florida. Review of this information will help assess which potential water management decisions could be implemented to sustain the current biological resources and dynamics of the bay.

REGULATORY TOOLS

Several regulatory tools could be used to protect inflow quantity within the Biscayne Bay watershed or portions thereof. Each option or tool meets different objectives and requires associated analyses. The different tools include minimum flows and levels, development of a public interest test rule under the requirements of Section 373.223(1), F.S., and water reservations. It is important to recognize that all the regulatory criteria may be updated over time based on new information.

Minimum Flows and Levels

In Florida, minimum flows and levels (MFLs) are developed pursuant to the requirements contained within the *Florida Water Resources Act*, specifically Sections 373.042 and 373.0421 of the Florida Statutes (F.S.). Minimum flows and levels are a part of a comprehensive water resources management approach intended to assure the sustainability of water resources. Minimum flows and levels are not intended as "stand alone" resource protection tools, but should be considered in conjunction with all other resource protection responsibilities granted to the water management districts.

Subsection 373.042(1)(a), 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 follows:

> "The minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

Significant Harm

The scope and context of MFL protection rests with the definition of "significant harm." The general narrative definition of "significant harm" proposed by the SFWMD (Rule 40E-8.021(31) of the Florida Administrative Code [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.

An example of the technical documentation to support MFL development is provided in **Appendix K** (Florida Bay MFL Document, SFWMD 2006). **Figure 2** provides some context to the MFLs statute, including the significant harm standard in relation to other water resource protection statutes.

Sustainability is the umbrella of water resource protection standards (Section 373.016, F.S.). Each water resource protection standard must fit into a statutory niche to achieve this overall goal. Pursuant to Parts II and IV of Chapter 373, surface water management and consumptive use permitting regulatory programs must prevent harm to the water resource. Water shortage statutes dictate that permitted water supplies must be restricted from use to prevent serious harm to the water resources. Minimum flows and levels are set to the point at which significant harm to the water resources, or ecology, would occur. The terms "harm," "significant harm," and "serious harm" are relative resource protection terms – each playing a role in the ultimate goal of achieving a sustainable water resource. The SFWMD has proposed that the conceptual relationship among these three terms can be represented, as shown in **Figure 2**.

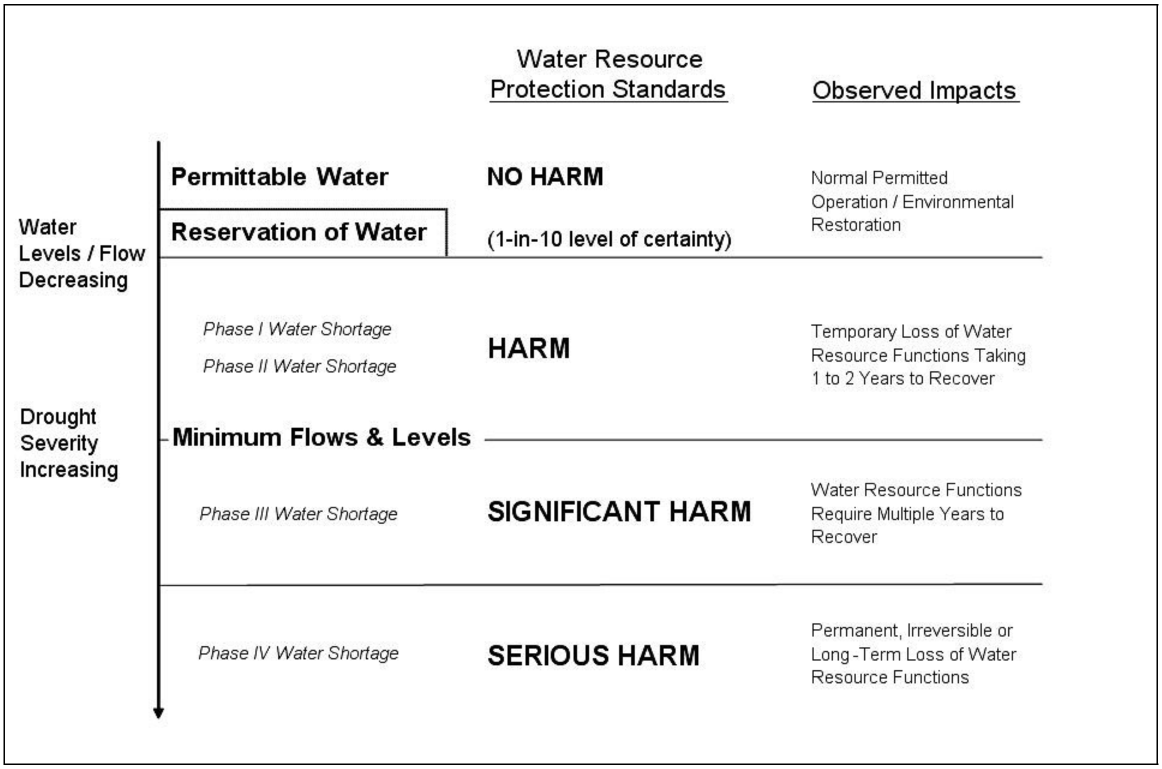


Figure 2. Conceptual relationship among the terms harm, significant harm, and serious harm. (Source: 40E-8.421, F.A.C.)

Regional Water Availability-Type Rule

The SFWMD Governing Board may choose to limit consumptive use withdrawals from the natural system under the public interest portion of the three-prong test for issuing consumptive use permits contained in Section 373.223(1), F.S. One example of this type of rule is the Regional Water Availability Rule, found in Section 3.2.1 of the Basis of Review for Water Use Permits (40E, F.A.C.)

More information about the water availability rule is available from: https://my.sfwmd.gov/portal/page?_pageid=1874,9680108&_dad=portal&_schema=PORTAL.

Water Reservations

A water reservation is a legal mechanism to set aside water for the protection of fish and wildlife or public health and safety from consumptive water use. Under Florida law, Section 373.223(4), F.S., the reservation is composed of a quantification of the water to be protected, which includes a seasonal and a geographical component. The state law on water reservations, in Section 373.223(4), F.S., provides for the following:

> The governing board or the department, by regulation, may reserve from use by permit applicants, water in such locations and quantities, and for such seasons of the year, as in its judgment may be required for the protection of fish and wildlife or the public health and safety. Such reservations shall be subject to periodic review and revision in the light of changed conditions. However, all presently existing legal uses of water shall be protected so long as such use is not contrary to the public interest.

WATER RESOURCE FUNCTIONS

The term "water resource" is used throughout Chapter 373, F.S. Each surface water body or aquifer serves a broad array of water resource functions. This is illustrated in Section 373.016, F.S., which includes flood control, water quality protection, water supply and storage, fish and wildlife protection, navigation, and recreation.

Florida's Water Resource Implementation Rule, Chapter 62-40, F.A.C., outlines specific factors to consider, including protection of natural seasonal changes in water flows or levels, environmental values associated with aquatic and wetland ecology, and water levels in aquifer systems. Other specific considerations include the following:

- Fish and wildlife habitat and the passage of fish
- Maintenance of freshwater storage and supply
- 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 when establishing inflow criteria using other available regulatory tools.

2

Hydrology

BACKGROUND

Establishing links between inflow or level (i.e., stage) and salinity is an important aspect of inflow evaluation. An understanding of the hydrology is essential to establishing links, including review of physical characteristics of the watershed and development of a water budget to quantify existing inflows.

Biscayne Bay is a shallow subtropical lagoon encompassing about 428 square miles (1,109 square kilometers). The watershed is about 938 square miles (2,429 square kilometers). Water depths are generally between 6 and 10 feet. The bay is located on the southeast coast of Florida, extending from the boundary between Miami-Dade and Broward counties south to the causeway that carries Federal Highway (US 1) to Key Largo and the boundary of Florida Bay. The City of Miami is the largest city within the watershed and most of the northern and central areas of the watershed are urban. The eastern boundary of Biscayne Bay is delineated by a series of narrow, offshore barrier islands. Along the mainland shoreline lies the longest stretch of mangrove forest on Florida's east coast. A large portion of the bay is encompassed within Biscayne National Park. Created in 1980, the park is located along the shoreline and adjacent coastal waters of south-central Biscayne Bay.

For the purposes of this review, Biscayne Bay encompasses three major regions – North, Central, and South (**Figure 3**). The North region of the bay extends from the Broward/Miami-Dade County line to the Rickenbacker Causeway. The largest urban area in south Florida—the City of Miami—lies adjacent to this region of the bay. The Central region extends from Rickenbacker Causeway south to the Turkey Point area. Because this region experiences a wide range of salinity, there is a relatively diverse assemblage of flora and fauna. The South region of Biscayne Bay extends from Turkey Point to the US 1 corridor that separates Biscayne Bay from Florida Bay, and includes Card Sound, Barnes Sound, and Manatee Bay.

Numerous freshwater inflow sources along Biscayne Bay's western shore include canals, tidal creeks, overland flow, and groundwater. A regional network of canals drains fresh water into the bay from developed areas of the watershed. The canal network is operated for flood control through the regulation of groundwater levels and the removal of storm water.

Figure 3. Map of Biscayne Bay showing the three regions – North, Central, and South. Note the Miami-Dade urban area, which encompasses much of the watershed and western shoreline. (SFWMD 2008)

The physical characteristics of different areas within Biscayne Bay vary considerably with respect to width, depth, water quality, and degree of connection to marine waters of the Atlantic Ocean. The bay encompasses a string of coastal lagoons, and ranges in width from extremely narrow (less than 200 meters) in the most northerly reaches to a width greater than 14 kilometers in the Central region. Water depths within the project area range from comparatively shallow (i.e., ~ 0.3 meters) within the intertidal areas to greater than 12 meters within dredged navigational channels.

A chain of narrow coral islands separates much of the bay from the Atlantic Ocean and restricts parts of the bay's circulation with the Atlantic Ocean. Salinity levels within the bay are driven primarily by: 1) direct rainfall and evapo-transpiration; 2) canal inflows; 3) overland sheet flow from marl-forming wetlands in the C-111 Basin and numerous small creeks; 4) groundwater, including upwelling by springs; and 5) mixing with waters from the Atlantic Ocean on the eastern boundary. Given the diffuse inflows and aerial extent of the bay, there is a great deal of spatial heterogeneity in salinity conditions. During wet periods, there may be a general gradient from low salinity near the western shores to the eastern boundary, particularly in proximity to inflow sources. During dry periods, however, conditions can be marine and even hypersaline in some nearshore areas. Tides range from 1.4 to 2 feet in areas open to tidal exchange. Where tidal exchange is limited, wind blowing predominately from the east and southeast largely determines circulations and mixing. Different areas of the bay have different sensitivity to flows depending on inflow source, wind direction, velocity, and residence times (**Appendix A**, ECT 2008).

The Biscayne Bay watershed can be characterized by four principal physiographic zones (**Figure 4**) situated contiguously from east to west: the Mangrove and Coastal Glades; the Atlantic Coastal Ridge; the Sandy Flatlands; and the southern Everglades (Fish and Stewart 1991).

East and south of the Atlantic Coastal Ridge are the Mangroves and Coastal Glades. This zone was formerly characterized by low-lying wetlands, but has been drained for farming and urban development. The Atlantic Coastal Ridge parallels the coast and has a width of 2 to 10 miles. The ridge varies in elevation from 8 feet above sea level in the south to 22 feet in the north and forms a natural barrier to drainage of the interior, except where breached by canals, rivers, or sloughs. West of the Atlantic Coastal Ridge in northeastern Miami-Dade County, the lower elevation Sandy Flatlands have a width of about 4 miles.

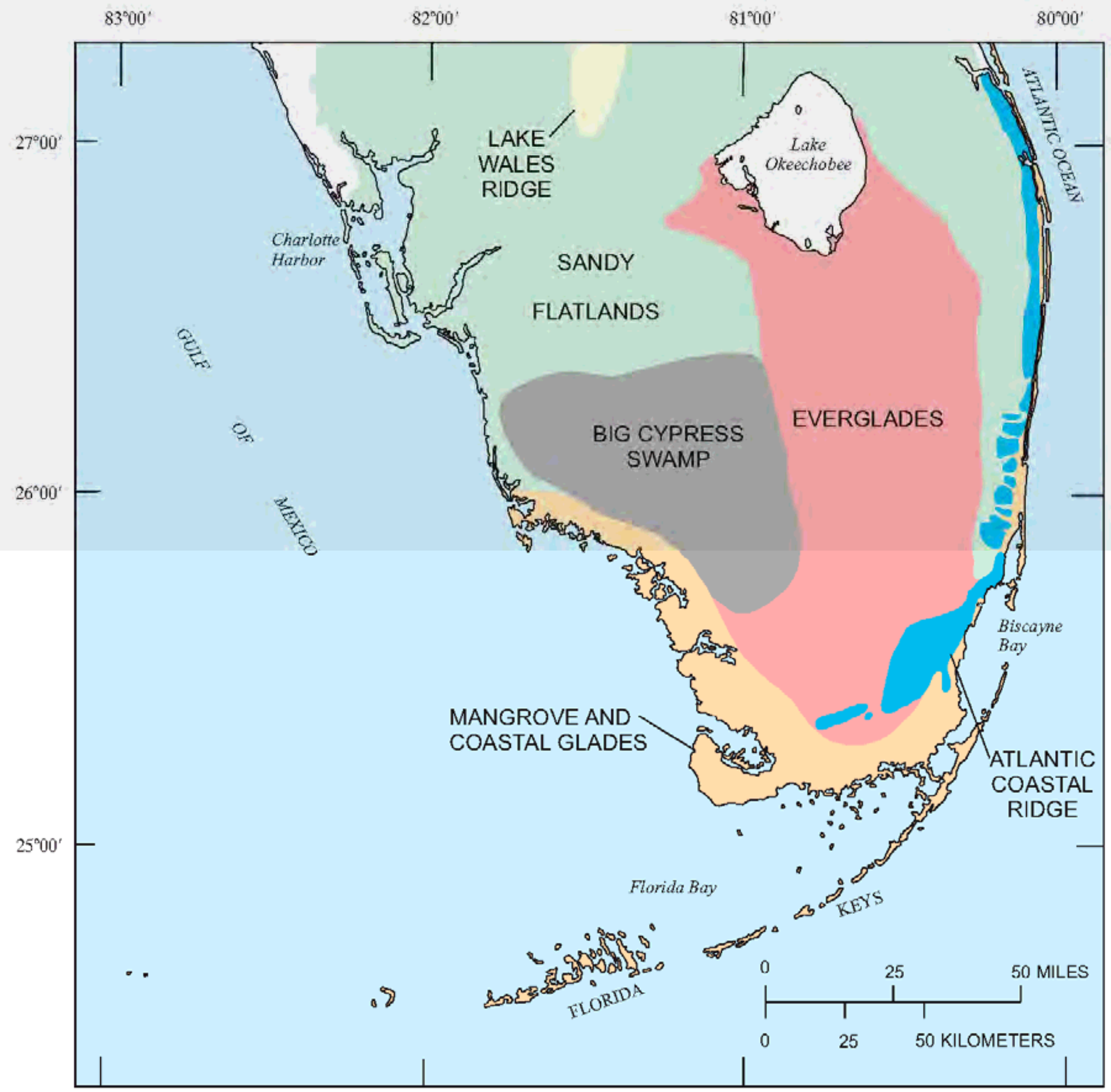


Figure 4. Biscayne Bay Watershed includes four physiographic zones situated contiguously from east to west: the Mangrove and Coastal Glades; the Atlantic Coastal Ridge; the Sandy Flatlands; and the Southern Everglades. (Source: Lietz 2000; modified from Parker, Ferguson, and Love 1955)

Before development, this zone was poorly drained and characterized by numerous intermittent ponds. West of the Sandy Flatlands, and slightly lower in elevation, the Everglades extend some 40 miles inland. The Everglades physiographic zone constitutes the remainder of the area and, except where drained for farming and urban development, has poor natural surface drainage, and is sparsely developed. Elevations within the Everglades range from 4 to 13 feet (1.2–4.0 meters) above sea level.

Biscayne Bay has experienced considerable environmental change due to a century of extensive regional population growth with considerable coastal and watershed development, including filling and dredging (Caccia and Boyer 2005). Numerous active municipal wellfields are located throughout the basin (**Figure 5**). The watershed also includes 33,588 hectares (ha) of agricultural lands that are located to the west and southwest of the bay. Vegetables, tropical fruit, and nursery plants are grown within this agricultural area.

The North region of the bay is heavily urbanized, 40 percent has been dredged or filled, and the shoreline is largely sea-walled (Caccia and Boyer 2005). The Central region of the bay lies between the heavily urbanized north and the less developed area to the south. Biscayne National Park's boundary begins in this region. The park receives input from the Miami River and is influenced by urbanized Key Biscayne, Coconut Grove, and Coral Gables. The land in the southern part of the Central region is relatively undeveloped, but contains canals, which drain landfills and urban and agricultural areas. In the South region, there are few canals, but inflows of fresh water have been significantly altered because of dredging and filling, mining, and construction of the C-111 Canal, Card Sound Road, and US 1, as well as other modifications upstream in the watershed. A large nuclear power generating facility operated by Florida Power and Light is located near Turkey Point on the border of the Central and South regions (**Figure 5**). The facility operates a large (5,900-acre) series of cooling canals (average temperature > 32°C) located adjacent to the bay, which contain hypersaline waters (ranging between 41 and 48 psu). This facility also creates a hydrologic barrier for freshwater overland inflows in this area.

Urban and agricultural land use has impacted the coastal habitats throughout the basin by decreasing the extent area of mangrove and coastal wetlands (including tidal creeks), as well as altering inflow patterns. Natural wetlands, which act as natural filters to reduce land contaminants, are significantly reduced in most areas, except in the South region of the bay. Wetlands in the South region have highly modified flow patterns and contain numerous exotic and invasive species (i.e., Brazilian pepper, lygodium, cattail).

Public lands in the North region include Oleta State Park, which lies adjacent to the bay. The Central region of Biscayne Bay is largely contained within Biscayne National Park (**Figure 5**). The land area of Biscayne National Park has a small fringing mangrove shoreline. In the South region, the eastern shore of Barnes Sound and western shoreline of north Key Largo are contained within the Crocodile Lake National Wildlife Refuge. In addition, there are public lands within the southern watershed owned by Miami-Dade County, the SFWMD, and other public agencies.

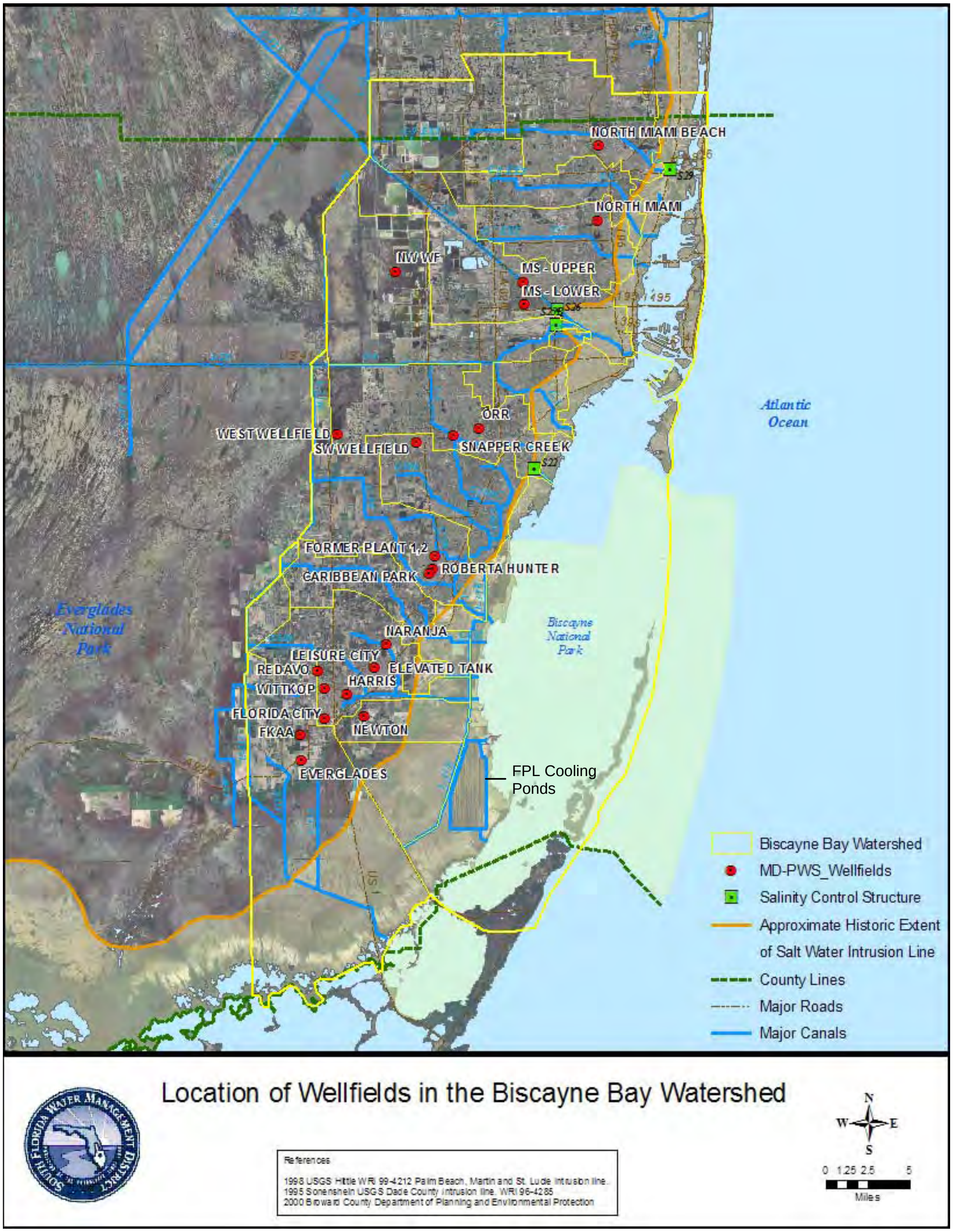


Figure 5. Location of wellfields in the Biscayne Bay watershed, and the inland boundary of saltwater intrusion into the Biscayne aquifer. (Source: SFWMD 2008)

MAJOR AQUIFER SYSTEMS

Two major aquifer systems underlie the Biscayne Bay watershed: the surficial aquifer system (SAS) and Floridan aquifer system (FAS). The FAS 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). It is overlain by a thick sequence of green clay, silt, limestone, and fine sand – collectively referred to as the intermediate confining unit. The SAS overlies the intermediate confining unit, and is the source of fresh water for most of southeast Florida. **Figure 6** shows a generalized cross-section of the aquifer systems in Miami-Dade County. The FAS in southeastern Florida contains brackish water and has no interaction with Biscayne Bay.

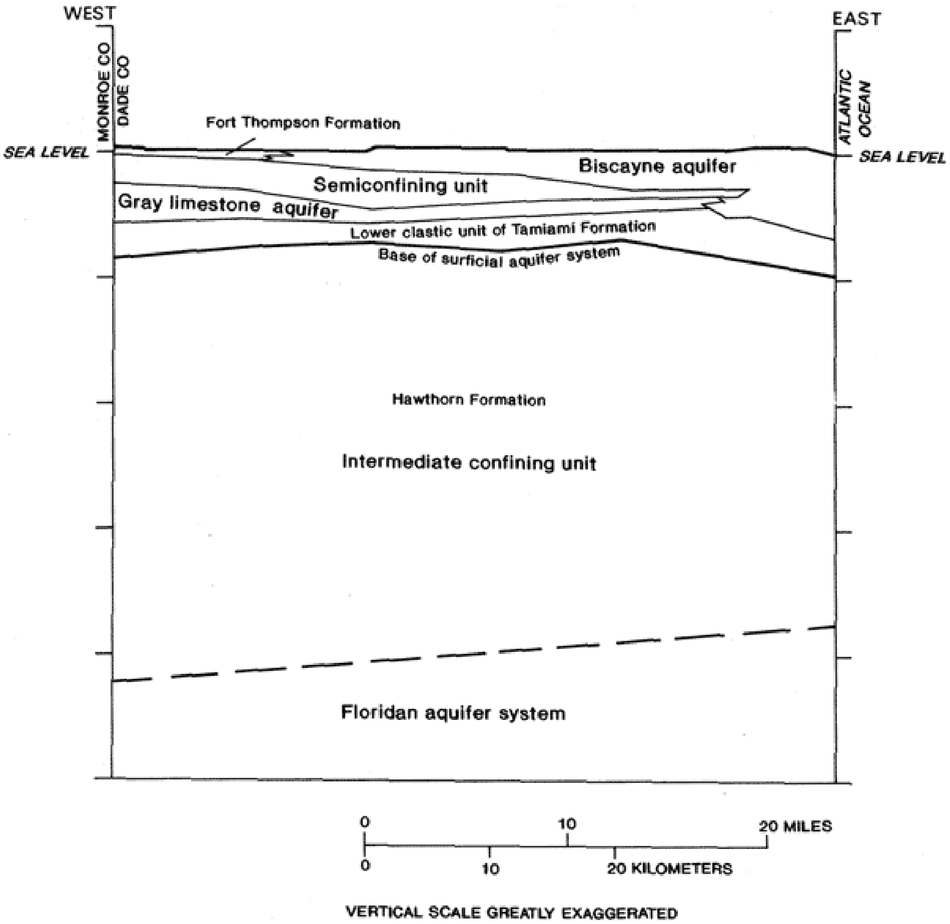


Figure 6. General cross-section of major aquifer systems in Miami-Dade County. (Source: Fish and Stewart 1991)

Surficial Aquifer System

The SAS 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 (**Figure 7**), which extends from coastal Palm Beach County south, including almost all of Broward County, all of Miami-Dade County, and portions of southeastern Monroe County.

The Biscayne aquifer is composed of interbedded, unconsolidated sands and shell units with varying thickness of consolidated, highly solutioned limestones and sandstones. In general, the Biscayne aquifer contains less sand and more solutioned limestone than most of the SAS. The Biscayne aquifer is highly permeable and has transmissivities in excess of 7 million gallons per day, per foot of drawdown (Parker, Ferguson, and Love 1955).

The major geologic deposits that compose 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 Plio-Miocene Age. However, in places where the upper unit of the Tamiami Formation contains highly permeable limestones and sandstones, the zones are also 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).

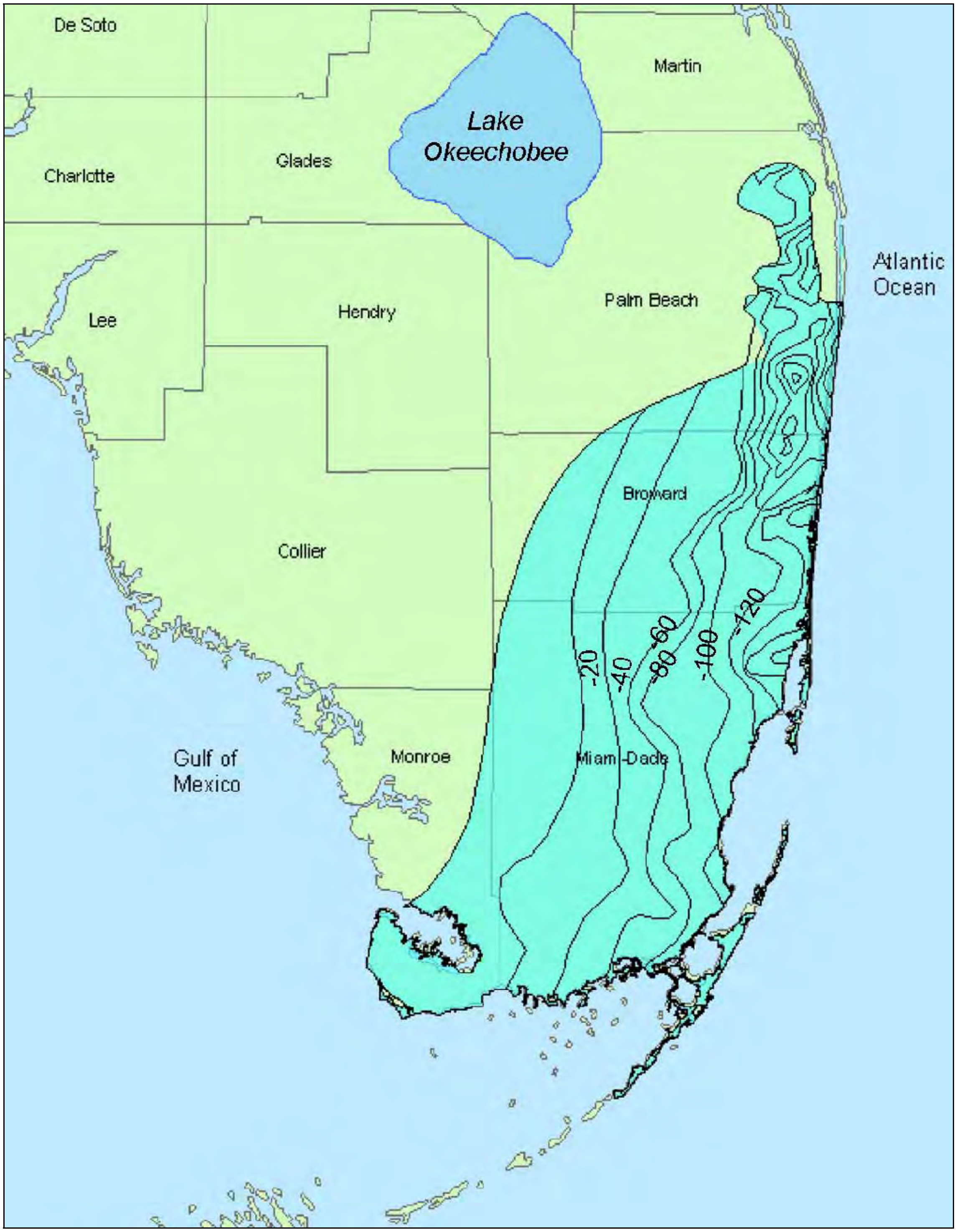


Figure 7. Location of the highly transmissive Biscayne aquifer (dark green) in eastern Miami-Dade, Broward, and Palm Beach counties with average aquifer depth in feet NGVD. (Compiled from Restrepo *et al.* 1992, Fish and Stewart 1991, and Shine, Padgett, and Barfknecht 1989.)

Floridan Aquifer System

The FAS is a confined aquifer system made up of a thick sequence of limestones, with dolomitic limestone and dolomite commonly found in the lower portions of the aquifer. It is separated from the SAS and confined by the sediments of the Hawthorn Group, which is also referred to as the intermediate confining unit. Less permeable carbonate units, referred to as the Middle confining unit, separate the FAS into two major aquifers called the Upper and Lower Floridan aquifers (UFA and LFA). The UFA is composed of fossiliferous limestones from the Suwannee, Ocala, and Avon Park formations. The Middle confining unit is relatively less permeable than both the UFA and the LFA. It separates the brackish water of the UFA from the more saline water of the LFA. The LFA 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). The FAS has no interaction with Biscayne Bay.

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 water availability in areas adjacent to saline water bodies. When water is withdrawn from the SAS 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 Central and Southern Florida Flood Control Project (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. This has resulted in a significant decline in groundwater flow towards the ocean and, consequently, has allowed 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).

Many studies have described the interaction of groundwater and marine surface waters in Miami-Dade County and documented the migration of the freshwater-saltwater interface, including Parker, Ferguson, and Love (1955), Kohout (1960), Kohout (1964), Langevin (2001), and Renken *et al.* (2005). Under pre-development conditions, fresh water was known to discharge from springs on the floor of Biscayne Bay (Parker, Ferguson, and Love 1955). Development of canal drainage works, restriction of natural overland surface water flow, and groundwater withdrawal for consumptive use altered the natural balance between fresh water and salt water, resulting in saltwater intrusion within the Biscayne aquifer (Renken *et al.* 2005). The freshwater-saltwater interface has moved progressively westward from the shoreline over much of Miami-Dade County and southern Broward County from 1945 through 1992 (Renken *et al.* 2005). A comprehensive depiction of the landward extent of saltwater intrusion in Miami-Dade, Broward, and Palm Beach counties in 1996 is shown in Renken *et al.* (2005) based on previous investigations (Broward County Department of Environmental Protection 1994; Sonenshein 1997; and Fitterman and Deszcz-Pan 1999). In 2005, the U.S. Army Corps of Engineers (USACE) and the SFWMD initiated investigations to evaluate the relationships between near-bay groundwater and bay water (**Appendix F:** Summary of Biscayne Bay Coastal Wetlands Investigations).

Several wells in southeast Broward County were taken out of service due to saltwater contamination as the recharge capacity of the aquifer was exceeded. The District's consumptive use permitting (CUP) criteria includes denial of permits that would cause harm to the water resources because of saline water intrusion. Section 3.4, Saline Water Intrusion, of the *Basis of Review for Water Use Permit Applications within the South Florida Water Management District* (SFWMD 2003) describes harmful saline water intrusion occurring when:

> "Withdrawals result in the further movement of a saline water interface to a greater distance inland toward a freshwater source except as a consequence of seasonal fluctuations; climatic conditions, such as drought; or operation of the Central and Southern Flood Control Project, secondary canal systems, 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 CUP Program has required water users to maintain a minimum of 1 foot of freshwater head between their wellfields and saline water as a guideline for the prevention of saltwater intrusion. This requirement, in combination with a saltwater intrusion-monitoring program, has been largely successful in preventing salt water from occurring. The Lower East Coast Water Supply 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.

CLIMATE, SEASONAL WEATHER PATTERNS AND RAINFALL

Florida is subtropical with a tropical savannah type climate characterized by a relatively warm wet season (May–October) and a cooler dry season (November–April). Mean annual temperature is 24.5°C, with a mean monthly low temperature of 20°C in January, and a mean monthly high temperature of 28°C in August (McIvor, Ley, and Bjork 1994). The area experiences distinct wet and dry seasons, high rates of evapotranspiration (ET), and climatic extremes of floods, droughts, hurricanes, and tropical depressions. Together, these factors plus regional water management operations represent the primary driving forces that regulate the amount of fresh water that can be directed towards Biscayne Bay.

During the wet season, showers occur nearly every day in response to afternoon sea breezes. Winds in south Florida follow a regular seasonal pattern—weak southeast trade winds and daily sea breezes in summer, persistent northeast winds in fall, and the regular passage of cold fronts—which cause moderate increases in wind speed and a clockwise rotation of wind direction in winter (Lee *et al.* 2002). Tropical depressions and hurricanes typically occur during the wet season on a fairly frequent basis of about once every one to two years. During the dry season, cold fronts usually pass through the region on a weekly basis.

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, centered over the Keys during July and August, winds generally diminish and rainfall decreases. Average winds and rainfall 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 Biscayne Bay. Average annual rainfall records collected from 1966–2001 for selected inland and coastal monitoring sites within Everglades National Park show that inlands sites were 1.6 times those recorded at coastal sites near Florida Bay (ECT 2005). Rainfall differences between the mainland and the bay are attributed to convective storms that 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 in comparison to what actually falls over the coastal waters (Schomer and Drew 1982).

Recorded annual rainfall values can vary significantly from year-to-year and interannual extremes in rainfall can have significant effects on Biscayne Bay's salinity regime. Trimble *et al.* (2001) has shown that low frequency meteorological modes associated with the El Nino-Southern Oscillation and the Pacific Decadal Oscillation can also have significant effects on the variability of south Florida rainfall and the amount of water available for urban and residential water supply. Enfield, Mestas-Núñez, and Trimble (2001) discuss the Atlantic Multidecadal

Oscillation and how fluctuations in North Atlantic sea surface temperatures can affect the amount of water available to the Everglades, south Florida estuaries, and agricultural and urban coastal communities.

Much of the rain that falls on Biscayne Bay is returned to the atmosphere by evaporation from water surfaces. Hydrologic and meteorologic methods are available to measure and/or estimate the combined rate at which water is returned to the atmosphere by transpiration and evaporation. The combined processes are known as evapotranspiration (ET).

South Florida, including Biscayne Bay, is periodically exposed to extreme weather conditions that may impact resources. Effects of a short-term or moderate storm or freeze may be transient, but severe freezes can result in large-scale destruction of sensitive species, such as mangroves, which may take many years to recover. The effects of major hurricanes may persist for decades or even longer. Nineteen severe cold waves (often termed freezes) affected the Florida peninsula between 1880 and 1980 (Myers 1986). Between 1880 and 1980, there were 22 years in which one or more hurricanes impacted the Florida Keys (Jaap 1984). 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. Many physical disturbances produced by hurricanes are uncontrollable. The alteration of hurricane runoff quantity and timing, quality of runoff water, and tidal exchange rates are aspects that can be controlled to some extent. Storms that affect the bay bottom and coastline occur at reasonably predictable intervals of one every three to five years, and storms that produce extreme freshwater runoff occur once every six to seven years. Given these frequencies, tropical storms may have significant impact on natural resources in south Florida.

SEA LEVEL RISE

Hydrologic alterations have not only been produced by local human activities, such as water management and land use, but also by larger scale changes in sea level. Sea levels in south Florida have risen at least 7.9 inches (20 centimeters) over the past 100 years (Wanless, Parkinson, and Tedesco 1994) and this change has likely affected the salinity regime of Biscayne Bay (Wingard *et al.* 2004). In particular, saltwater intrusion in the South region of the bay has expanded the inland boundary of the salinity intrusion line (**Figure 5**) and increased the magnitude of salinity in this area. These alterations have been driven by both sea level rise and reduced freshwater inflow and groundwater levels.

It is not expected that sea level rise will have a significant effect on the connection between freshwater inflow and salinity in the near future. However, it is important to recognize sea level rise in the context of overall watershed and coastal planning efforts. Accelerated sea level rise over the next couple of decades may increase the potential for saltwater intrusion in vulnerable areas. An increase in freshwater head that may be needed to minimize saltwater intrusion will have the compounding effect of increased flood risk in some areas. Low elevations, particularly in the South region, may be vulnerable to further saltwater intrusion of coastal areas.

HYDROLOGIC HISTORY

Historically, the Everglades, Biscayne Bay, and Florida Bay were part of a larger hydrologically connected system of wetlands, tidal creeks, and coastal lagoons with Biscayne Bay serving as the eastern outlet of the Everglades (Davis 1943; Parker, Ferguson, and Love 1955). Fresh water flowed overland to Biscayne Bay through natural sloughs and rivers, and as groundwater through the Biscayne aquifer (Buchanan and Klein 1976; Kohout and Kolipinski 1967; Parker, Ferguson, and Love 1955). This pattern has been significantly altered over the past 100 years by regional drainage; groundwater use; canal construction and operation; urban development; construction of roads and levees; and other changes to natural groundwater and overland flows. Construction of major canals within the watershed and dredging of natural tributaries and transverse glades that carried fresh water to Biscayne Bay have resulted in lowered regional and coastal water tables (Parker, Ferguson, and Love 1955); reduced water storage in the watershed; decreased groundwater flow to the bay; and the elimination of natural creeks. The timing and distribution of flow into the bay has been altered due to urbanization of the watershed.

Given the changes and urbanization within south Florida, it is important to recognize on a regional scale how fresh water flowed into Biscayne Bay prior to the alterations of the past century. At the end of the last glacial period, about 10,000 years ago, sea level was from 10–20 meters below where it is today. The central areas of south Florida consisted of a dry sandy ridge and the Everglades peatlands did not exist. Lake Okeechobee was a shallow basin or depression about 10 feet deep with a rock and sand shoreline along its southern edge. Since that time sea level has been rising steadily, associated with a rise in groundwater levels. The Everglades peatlands began to form about 5,000 years ago. 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 wind-blown nutrients, this basin gradually filled with marl and organic sediments. As sea levels continued to rise, the level of the landscape also rose over time. Sediment and soil accretion also allowed water levels in Lake Okeechobee to increase to higher levels, providing additional storage to ensure that water flowed out of the lake progressively later in the dry season.

When humans encountered south Florida, about 500 years ago, freshwater inflow occurred primarily as rainfall, overland sheet flow across the mangrove wetlands, and flow through coastal creeks and rivers. By the early 1800s, the lake 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 southward across a very gradually-sloping plain, which varied in vegetation composition from north to south.

Watershed Changes

Beginning in the late 1800s, efforts to drain the main body of the original Everglades irreversibly altered hydrologic conditions throughout south Florida. In the early 1900s, flow patterns to Biscayne Bay began to change with the construction of major drainage canals. In addition, development and associated projects within the bay and adjacent coastal areas began to occur (**Table 1**). These efforts interrupted the flow of water southward out of Lake Okeechobee into the Everglades and increased the volume of water draining east into the Atlantic Ocean. In the early 1970s, a nuclear power facility went on-line near Turkey Point, which contains a hypersaline cooling canal system adjacent to Biscayne Bay. An expansion of this facility is currently proposed and a monitoring plan is being developed.

Water management activities that currently have the most direct effect on the supply of fresh water to the South region of the bay began in the 1960s and continued through completion of the C&SF Project in the 1970s (**Table 2**). The completion of the C-111 Canal in 1968 allowed water managers to fully regulate the flow of surface water into the South region, as well as west into Everglades National Park and northeastern Florida Bay.

By the early 1970s, there was sufficient concern about the impact of water management on Everglades National Park to motivate a series of actions intended to mitigate the effects of the structures and practices put in place. Modifications to the water management system and the operations continued over the next 30 years (**Table 2**). Beginning in the late 1970s, a program of minimum prescribed water deliveries set monthly targets for the quantity of water to be supplied to Shark Slough, across Tamiami Trail, to Florida Bay through the C-111 Canal, and for discharge into the headwaters of Taylor Slough. In the early 1970s and continuing until 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 in the region east of the headwaters of Taylor Slough, near the main entrance to Everglades National Park. In the early 1980s, flooding concerns in Miami-Dade County prompted additional operational changes to the SDCS in an attempt to alleviate flooding and provide additional fresh water to Everglades National Park. Structural changes were also planned and made to implement a more even distribution of flows from the C-111 Canal across the mangroves.

Table 1. A partial history of major drainage and development activities within the Biscayne Bay watershed over the past 100 years. (Adapted from: NOAA 2000)

Year	Drainage or Development Activity
1896	Flagler's Florida East Coast railroad extends to Miami, City of Miami Incorporated
1896	Channel dug from Cape Florida to Miami River, Port of Miami opens
1897	Flagler builds Royal Palm Hotel on Miami River, city grows around hotel
1903	Canals drain coastal wetlands changing hydrology of Everglades and Florida Bay
1904	Saltwater intrusion begins
1904-1905	Government Cut, spoil used to construct Lummus, Dodge and Fisher islands
1908	Miami River rapids dynamited
1910-1911	Portions of Miami Canal constructed
1912	Belle Isle constructed
1912-1913	Snapper Creek and Cutler Canals, Coral Gables Waterway and Collins Canal built
1913	Miami River dredged, Collins Bridge causeway constructed
1913-1920	Mangroves cut down and swamps filled
1915-1920	Tourism and number of permanent residents increase leading to accelerated development of the Miami area
1917	Star Island constructed
1918	County Causeway built, later renamed MacAthur Causeway
1914-1919	Bakers Haulover completed
1918-1922	Hibiscus Island, Palm Island, Rivo-Altro, and Di Lido islands built
1920s	Port of Miami becomes primary hub for all shipping to south Florida
1925	Intracoastal Waterway constructed, Bayview section of Miami Shores filled, area east of Biscayne Blvd. filled to create Bayfront Park
1922	Flagler Monument built on spoil island
1924	Fair Isle constructed
1925	Venetian Causeway replaces old Collins bridge
1928	79th Steet Causeway built
1930s	Port of Miami provides passenger service to Havana, Cuba
1930s	Miami River contaminated from commercial development and sewage
1930s	Islands of North Bay Village
1934	Environmental concerns about Miami River begin
1940s	Saltwater intrusion arrested, but problems remain
1941-1945	WWII, U.S. Navy assumes control of Port of Miami
1942	Construction of Richmond Naval Air Station
1943	Rickenbacker Causeway built

Table 1. A partial history of major drainage and development activities within the Biscayne Bay watershed over the past 100 years (Continued).

Year	Drainage or Development Activity
1943	Homestead Army Air Field constructed
1943	Bay Harbor Islands built
1950s	Southern quarter of Key Biscayne bulk-headed and filled
1951	Broad Causeway constructed
1960-1961	Julia Tuttle Causeway built
1964	Dodge Island Seaport opens
1965	Turkey Point power plant opens
1967	Biscayne National Monument established
1970s	Dredge and fill activities at Fair Isle
1972-1973	Turkey Point nuclear unit goes online
1980	Biscayne National Monument expanded and renamed Biscayne National Park
1981	Port expands to Lummus Island
1991	Port records a record 3.9 million tons of cargo handled in one year
1992	Hurricane Andrew causes widespread destruction in Miami area
1999	Largest cruise ship in the world is based at Port of Miami

Table 2. Water management activities affecting the South region of Biscayne Bay from 1960 through 2000. (Adapted from: SFWMD 2006)

Period	Water Management Activities
1960 - 1969	Construction begins on C-111 and associated canals that will alter the hydrology in south Miami-Dade County. 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. An earthen plug is installed at present location of S-197 Structure to prevent saltwater intrusion by maintaining water levels above sea level in the lower reaches of the C-111 Canal.
1970 - 1979	Work begins on the South Dade Conveyance System (SDCS) that are needed to implement the Minimum Schedule Water Deliveries (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 free discharge of flood waters through the C-111 Canal; this eventually leads to construction (in 1992) of the present, gated control structure. The S-133 pump is installed to increase the capacity to move water from wetlands north of Tamiami Trail into southern Miami-Dade County through the C-111 and L-31N canals.
1990 - 2000	In 1997, removal of the spoil mound along the C-111 Canal, south of S-18C, allows a more even east-west distribution of discharge into the wetlands north of Florida Bay and southern wetlands of Biscayne Bay.

MANAGEMENT OF FRESHWATER FLOW

Drainage from eastern Miami-Dade County into Biscayne Bay is primarily controlled by the system of canals, levees, and control structures constructed as part of the Central and Southern Florida Flood Control Project (C&SF Project). The C&SF Project canals in eastern Miami-Dade County were built to provide flood protection with secondary uses that include drainage for agriculture and urban development, maintenance of groundwater table elevations to mitigate saltwater intrusion, and water supply for irrigation and local wellfield recharge. The C&SF Project control structures regulate the flow of water in the canals, control the discharge of excess water during flooding, and detain runoff during drought periods. Although the coastal structures prevent salt water from a tidal or storm surge from entering canals and moving inland, tidal structures have been overtopped by hurricane tides. Seventeen canals in eastern Miami-Dade County are operated by the District and provide the basis for surface water management in the county and freshwater flow into Biscayne Bay (**Figure 8**). Canal flow into the bay occurs through 14 major coastal structures (not including GB58). Detailed information on the system of canals, levees, and control structures in eastern Miami-Dade County are contained in Cooper and Lane (1987) and are summarized in **Appendix I**: Description of Miami-Dade County Drainage Basins.

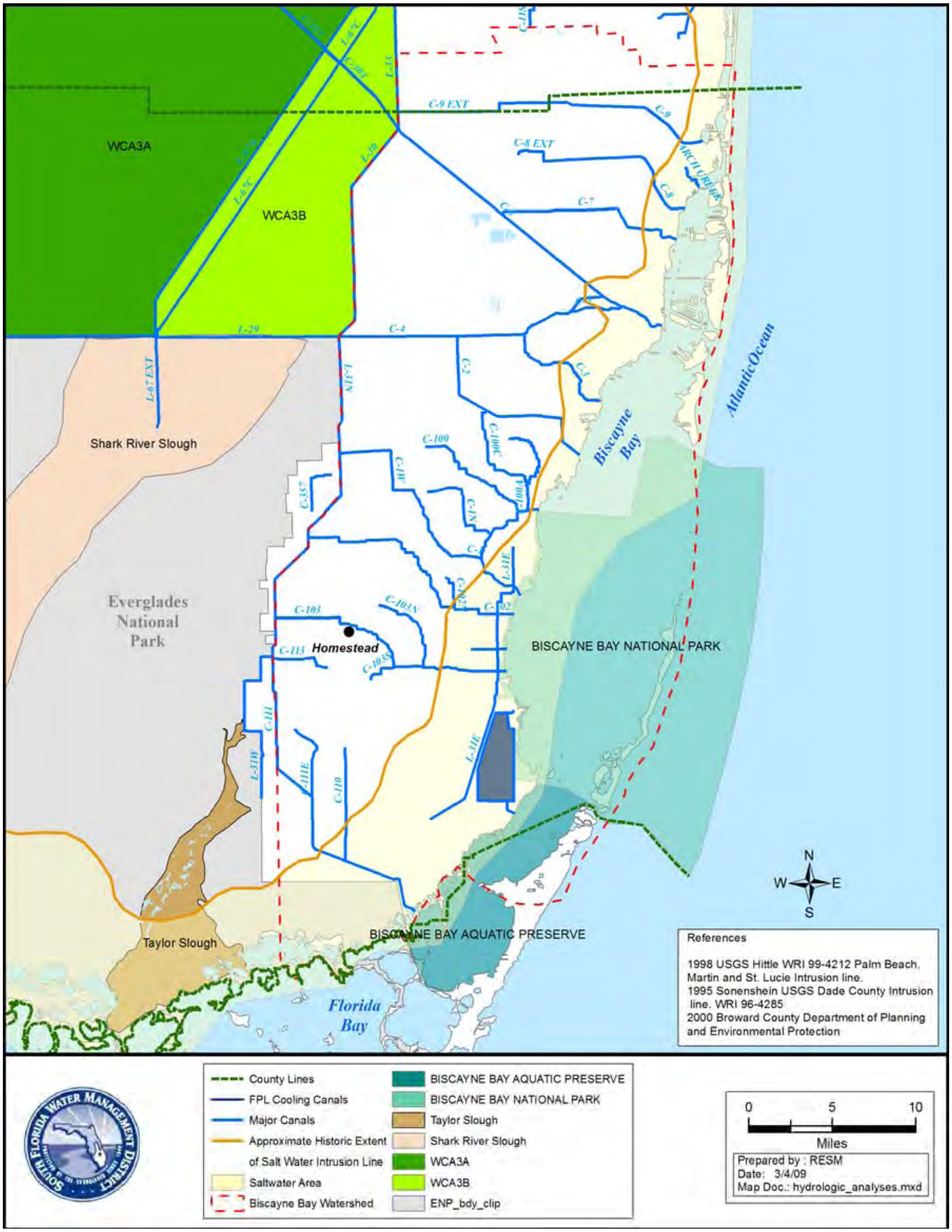


Figure 8. Seventeen canals in eastern Miami-Dade County are operated by the District and provide the basis for surface water management in the county and freshwater flow into Biscayne Bay. (Source: SFWMD 2008)

HYDROLOGIC ANALYSES

Salinity in coastal environments responds to fluctuations in fresh water. The freshwater inflows are mediated by exchange and mixing between the ocean and freshwater inputs. Components of the freshwater budget consist of rainfall, evaporation, and inflows from the watershed. In Biscayne Bay, these inflows consist of canal inflow, ungauged surface inflow from coastal wetlands, and groundwater. Salinity responds to changes in the net supply of fresh water, which is the sum of rainfall plus all inflows from the watershed minus evaporation. The influence of any one component of the water budget occurs in proportion to its magnitude and adds to or subtracts from the influence of the other components. Of all of the components of the freshwater budget in Biscayne Bay, only canal inflows are routinely monitored; these daily flow data extend back to 1986.

Several water budgets have been developed for the watershed, but only Wang, Luo, and Ault (2003) have compiled a full freshwater budget for the bay. Wang, Luo, and Ault (2003) used rainfall measured at the Mowry Canal, located adjacent to the South Central Inshore subarea, and pan evaporation measured at Royal Palm, west of Florida City, to estimate these components for the entire bay. Other studies focus on estimating inflow from the watershed, including the contribution from ungauged surface inflow and groundwater inflow based on simulations of the water budget on the watershed. For example, Langevin (2001) estimated total inflow based on output from SEAWAT, a variable density groundwater model. Various evaluations using either empirical inflow/salinity relationships or numerical models have also been conducted for Biscayne Bay.

Several hydrodynamic models have been developed for Biscayne Bay, including Wang, Luo, and Ault (2003) and the U.S. Army Corps of Engineers' multidimensional hydrodynamic model TABS-MDS. While this hydrodynamic modeling exists for certain areas, a system-wide approach is needed for initial evaluation of regulatory options, which include a water budget and long-term (several decades) salinity estimates spanning a range of climatic conditions. Environmental Consulting and Technology, Inc. (ECT) was contracted to compile a system-wide water budget and produce salinity estimates over a 36-year period of record. The results are summarized in the *Biscayne Bay Freshwater Budget and Relationship of Inflow to Salinity* final report and the subsequent update is provided in **Appendix A** (ECT 2008). The update was prepared based on District comments to the initial report.

In the ECT evaluation, the study area within Biscayne Bay was divided into eight subareas based on the presence of causeways or natural land features that restrict exchange between areas, inlets that exchange water with the ocean, and canals that provide freshwater inflow (**Appendix A**). A mass balance model using the South Florida Water Management Model (SFWMM) Base 2000 case as input flows was used to develop a water budget for each of the eight subareas (termed "base case water budget"). The mass balance calculations were used to synthesize a time series of monthly salinity values for each subarea of the bay based on a 36-year water budget using assembled data (termed “synthetic salinity record”).

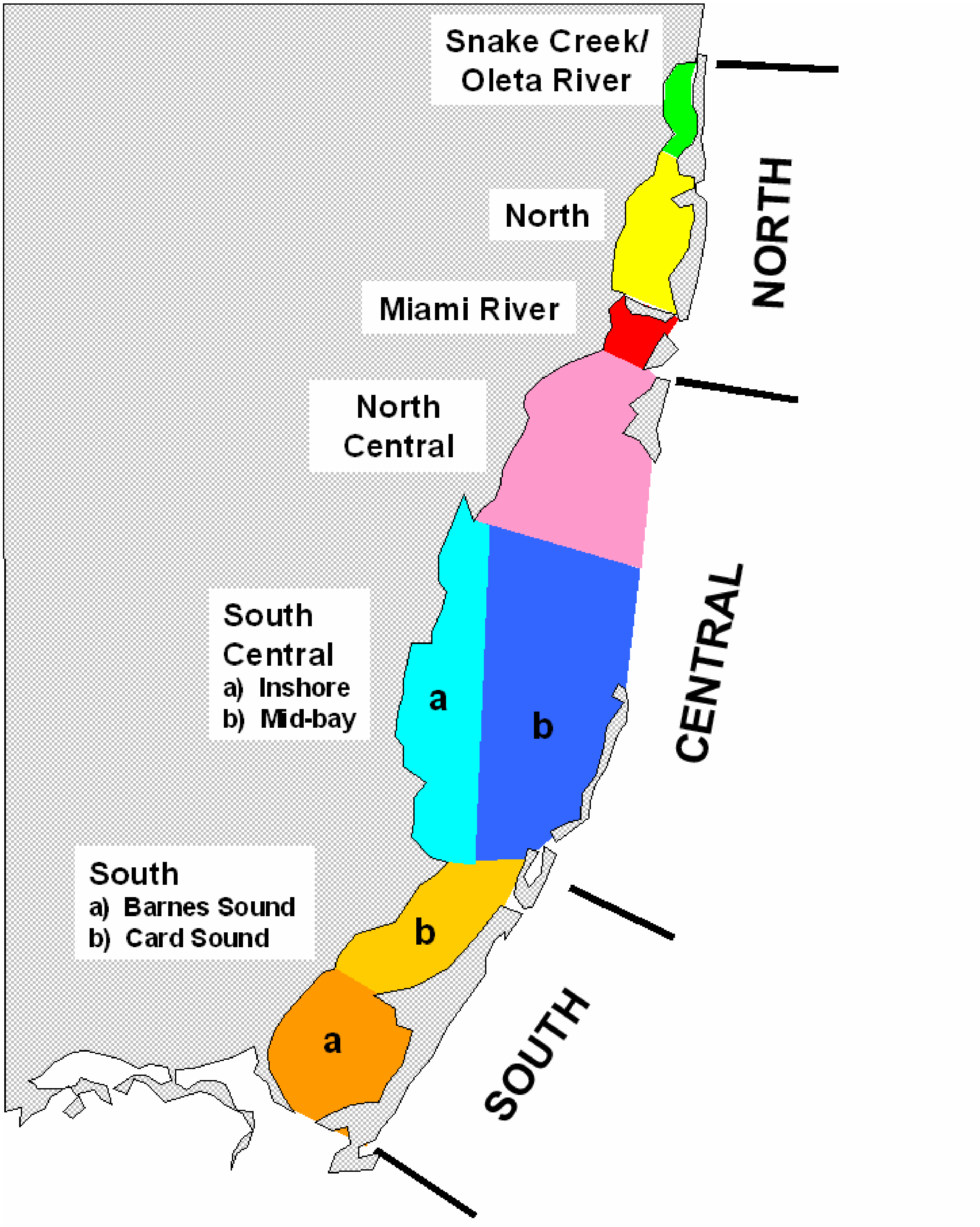


Figure 9. Biscayne Bay is divided into three geographic regions (North, Central, and South) and eight subareas for hydrologic analyses. (Source: Appendix A, ECT 2008)

Water Budget

The components of the compiled 36-year water budget derived from the SFWMM base case are shown for each of the eight subareas in **Table 3**. This analysis assumes year 2000 water management conditions and land use, and climatologic data from the 36-year period of 1965–2000. Canal inflows were calculated through 14 major coastal structures. In the North region, (i.e., subareas, including Snake Creek/Oleta River, north, Miami River) canal inflows through six major structures contribute the largest inflow both on a volume basis and normalized for surface inflow. Both groundwater and canal inflow are relatively important components in the Central region (i.e., subareas, including North Central and South Central) on a volume basis, where canal inflow into the bay is through seven structures. In the South region (i.e., subareas, including Barnes Sound and Card Sound), the total inflow is relatively small in comparison to the other regions with very little canal flow through one structure. The combination of ungauged overland and groundwater are thus major inflow sources in this region.

Differences in the relative influence of the canal inflows in the water budget (**Table 4**), are evident by subarea and region. The time that would be required for the entire volume of the subarea to be displaced by freshwater inflow at the long-term average rate (i.e., freshwater displacement) is dissimilar for each region, ranging from 2.2 months in the North region to 60 months in the south.

Watershed water budgets compiled for a dry year, a wet year, and a normal year illustrate the range of variation in the freshwater budget encompassed by existing conditions for hydrology. The three years selected for this purpose are identified based on a comparison of lists of years ranked by the annual amount of rainfall in Biscayne Bay and in the National Climatic Data Center (NCDC) Florida Climate Division 5. Climate Division 5 encompasses the Everglades wetland in the central part of Florida. The objective in selecting the wet, dry, and normal years is to identify years based on variation in rainfall that occur over the entire South Florida Water Management District, not just the variation in rainfall patterns isolated along the coast.

The years selected from two sources (see Appendix A, ECT 2008) for comparison are 1990 (dry), 1995 (wet), and 1993 (normal). The wet and dry years fall within the top four wettest or driest years from each source (**Table 5**). This translates into a return frequency of approximately 1-in-10 for the dry and wet conditions characterized by this 36-year record. Comparison of water budgets for wet, dry, and normal years reinforces and expands upon the regional differences (**Table 6**). The general spatial pattern of decreasing freshwater inflows from north to south in the bay is exacerbated under dry conditions. The South region receives little or no inflow from canals in the dry and normal years. Inflows of ungauged surface water and groundwater account for a greater portion of the water budget in both the Central and South regions under dry rainfall conditions. The volume of storage in the aquifer becomes the critical component during the times when losses through evaporation are high and rainfall is low, which typically occurs toward the end of the dry season each year. In dry years, due to relatively low freshwater inputs, the net freshwater supply in the South region can be negative. The movement of saltwater intrusion in the Biscayne aquifer corresponds to this long-term pattern of negative freshwater supply.

Table 3. Components of the base case freshwater budget in volume units (upper panel) and volume normalized by surface area of the receiving water body (lower panel). (Source: Appendix A, ECT 2008)

Subarea	Rainfall (1,000 ac-ft)	Evap. (1,000 ac-ft)	Inflows (1,000 ac-ft)		
			Canals	Ungauged Overland	Ground-water
Snake Creek/Oleta River	4.8 -4.9		166	*0	6.7
North 50		-50	157	*0	17
Miami River	17	-17	206	*0	7.8
North Central	162	-166	166	*0	36
South Central - Inshore	124 -14	2	205	17	**64
South Central - Mid-bay	248 -284		n.a.	n.a.	n.a.
South – Card Sound	62	-80	0	*0	**17
South - Barnes Sound	74	-96	14	56	**6
All Biscayne Bay	743	-840	914	73	155

Subarea	Rainfall (cm)	Evap. (cm)	Inflows (cm)		
			Canals	Ungauged Overland	Ground-water
Snake Creek/Oleta River	140 -14	4	4861	*0	195
North 14	7	-145	457	*0	50
Miami River	146	-146	1768	*0	67
North Central	143	-146	147	*0	32
South Central - Inshore	129 -14	8	213	18	**67
South Central - Mid-bay	129 -148		n.a.	n.a.	n.a.
South – Card Sound	117	-149	0	*0	**33
South - Barnes Sound	116	-150	22	87	**9
All Biscayne Bay	131	-148	160	13	27

* Zero inflow based on calculations by the SFWMM Base 2000 scenario.

** Results by Langevin (2001) suggest that groundwater discharges into coastal wetlands rather than as submarine groundwater discharge directly into the bay.

Table 4. Relative influence of canal inflow in the water budget.
(Source: Appendix A, ECT 2008, revised Sept. 2008)

Subarea	Area (mi^2)	Canal Inflow (1,000 ac-ft)	Ratio of Canal to Total Inflow	Ratio of Net Rainfall* to Inflow	**Freshwater Displacement (months)
Snake Creek/Oleta River	1.6 16	6	0.96	0.00	0.62
North 16		157	0.90	0.00	4.3
Miami River	5.6	206	0.96	0.00	1.9
North Central	54	166	0.82	-0.02	19
South Central - Inshore	46 20	5	0.72	-0.06	6.0 ***(31)
South – Card Sound	25	0.0	0.00	-0.99	****n.a.
South - Barnes Sound	30	14	0.18	-0.29	31
Region					
North 24		529	0.94	0.00	2.2
Central 19	1	371	0.76	-0.12	26
South 56		14	0.15	-0.43	60

* Net rainfall is the sum of rainfall minus evaporation.

** Freshwater displacement is the time that would be required for the entire volume of the subarea to be displaced by freshwater inflow at the long-term average rate.

*** Freshwater displacement time increases to 31 months when South Central Inshore and Mid-bay subareas are combined.

**** Freshwater displacement time is influenced by an additional, unknown amount of inflow from Barnes Sound.

Table 5. Ranked total annual rainfall (cm) derived from two sources and used to illustrate dry (1990), wet (1995), and normal (1993) years. (Source: Appendix A, ECT 2008)

Year	SFWMM Rainfall (cm/yr)	Year	NCDC Div. 5 Rainfall (cm/yr)	
1989 87.	2 19	88	108.4	
1974 10	4.0 20	00	108.4	
1990	**104.0**	1981 10	8.7	
1970 10	5.4	**1990**	**109.9**	**DRY**
1975 10	6.9 19	76	111.8	
1971 10	7.9 19	85	112.5	
1987 11	6.6 19	71	113.5	
1980 11	7.3 19	89	115.3	
1985 11	8.5 19	80	115.8	
1986 11	9.4 19	67	116.1	
1998 12	2.9 19	75	117.6	
1988 12	3.0 19	96	119.8	
1984 12	3.7 19	73	121.1	
1993	**124.7**	1984 12	3.0	
2000 12	5.4 19	74	124.3	
1976 12	5.5 19	77	125.6	**NORMAL**
1999 12	5.8 19	72	126.1	
1979 12	6.7 19	65	127.3	
1992 12	7.3 19	86	131.3	
1978 12	9.5 19	87	134.1	
1981 13	1.8	**1993**	**135.9**	
1977 13	2.1 19	78	136.8	
1973 13	3.3 19	92	136.8	
1996 13	3.4 19	79	137.2	
1965 13	3.8 19	70	137.5	
1991 14	0.3 19	66	140.1	
1972 14	5.8 19	98	140.4	
1967 15	1.3 19	97	146.2	
1982 15	2.0 19	99	148.2	
1983 15	3.5 19	91	148.7	
1994 16	3.6 19	82	153.0	
1997 16	4.8 19	68	153.5	
1966 17	1.7 19	94	154.8	
1995	**176.6**	1969 16	1.1	**WET**
1969 18	5.6 19	83	161.1	
1968 18	8.6	**1995**	**178.7**	

Table 6. Summary of freshwater budget components reported as volume (in 1,000 ac-ft/year) for wet, dry, and normal years. (Source: Appendix A, ECT 2008)

	Dry Year - 1990	Normal Year - 1993	Wet Year - 1995
Budget for North Region:			
Rainfall	54	65	92
Evaporation	-73	-72	-71
Net Rainfall	-19	-6	21
Canal Inflow	303	567	765
Ungauged Wetland Inflow	0	0	0
Groundwater Inflow	25	32	40
Net	**309**	**593**	**825**
Budget for Central Region:			
Rainfall	435	512	720
Evaporation	-594	-593	-580
Net Rainfall	-160	-81	140
Canal Inflow	173	413	741
Ungauged Wetland Inflow	13	15	26
Groundwater Inflow	83	107	122
Net	**110**	**455**	**1029**
Budget for South Region:			
Rainfall	107	128	186
Evaporation	-176	-176	-173
Net Rainfall	-69	-49	13
Canal Inflow	0	2	36
Ungauged Wetland Inflow	30	51	93
Groundwater Inflow	9	28	45
Net	**-29**	**31**	**187**
Budget for All Regions:			
Rainfall	595	705	998
Evaporation	-843	-840	-824
Net Rainfall	-247	-136	174
Canal Inflow	477	980	1506
Ungauged Wetland Inflow	44	65	120
Groundwater Inflow	117	167	206
Net	**390**	**1077**	**2006**

Salinity Patterns

Salinity has been measured in Biscayne Bay for a number of years. The longest, most consistent records of salinity data have been collected and maintained by Miami-Dade County Department of Environmental Resources Management (DERM). Many of the DERM's sites were established in 1979, and consist of monthly grab samples. A second monitoring program was established in 1993 by Florida International University's Southeast Environmental Research Center, which also consists of monthly grab samples. A third source of data is available from fixed salinity recorders deployed by Biscayne National Park. Most were established around 1997. The Atlantic Oceanographic and Meteorological Laboratory (AOML) of the National Oceanographic and Atmospheric Administration have collected shipboard salinity data on a monthly basis in southern Biscayne Bay since 2002. **Appendix C**: Salinity Observations shows time series of salinity observations from DERM sampling stations, Biscayne National Park stations, and AOML surveys. Measured observations throughout Biscayne Bay illustrate the potential for hypersaline conditions during dry periods, particularly in the Central and South Inshore areas. Salinity in excess of 40 psu has been observed in several stations during two dry periods – in the late 1980s to early 1990s (**Table 5**), and more recently from 2005 to 2007.

Monthly salinity time series produced from the base case water budget are summarized in **Figure 10** and **Table 7**. The effects of uncertainty relative to frequency of hypersalinity (> 40 psu) were evaluated by increasing or decreasing each component of the water budget (**Appendix A**, ECT 2008). Rainfall, evaporation, and bathymetry were the most sensitive elements relative to this metric. Regional differences in salinities reflect differences seen in the freshwater budget. The greatest range of variation in salinity occurs in the South region where, due to low rates of exchange, long residence time allows the salinity of wetter and dryer than average conditions to persist and accumulate from one year to the next. The net freshwater supply to the South region is low. Ample net freshwater supply is present in the North region of the bay, owing to the large quantity of canal inflow relative to estuarine volume. Even so, vigorous exchange with the ocean maintains salinity values close to seawater values (~36 psu), and this attenuates the range of salinity variation in response to variation in the supply of fresh water (**Figure 10**, **Table 7**). In the Central region, salinity in the South Central inshore subarea is lower on average, even though subareas in the region receive less fresh water than in the North. Shallow water depth and a lower rate of exchange with the ocean contribute to a greater salinity responsiveness to fluctuations in the net supply of fresh water. The net freshwater supply to the South region is low, leading to high salinity values in dry years. In addition to little exchange with the ocean, Card Sound and Barnes Sound have the potential to the develop hypersaline conditions at the end of the dry season and during drought periods.

Using stable isotope techniques, salinity variations close to the mainland of Biscayne Bay were found to be influenced primarily by discharge from canals and groundwater (Swart and Price 2004).

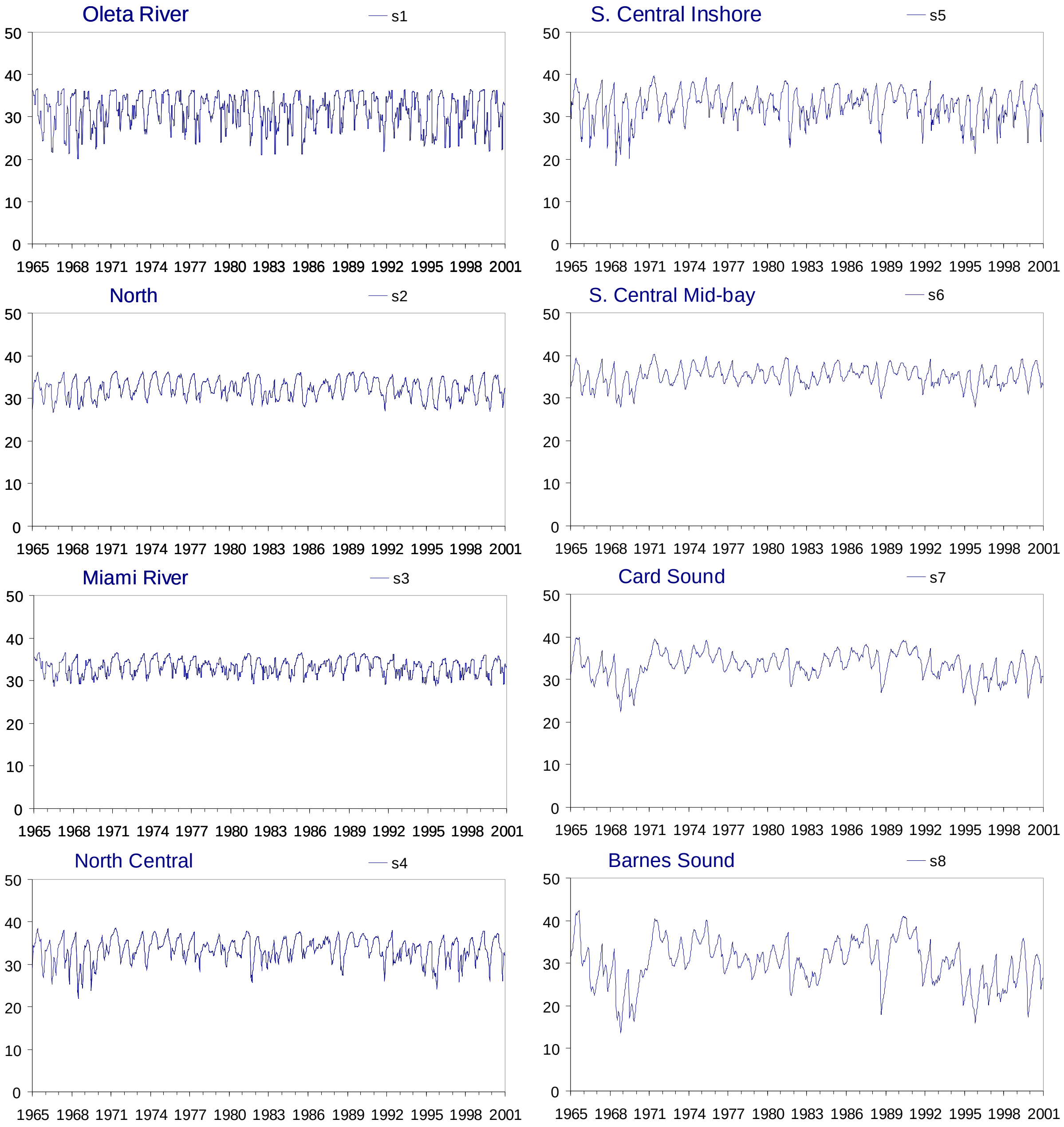


Figure 10. Salinity estimation (psu) calculated from the base case (SFWMM Base 2000) water budget. Monthly Average Salinity (shown on Y-axis). (Source: Appendix A, ECT 2008, revised Sept. 2008)

Table 7. Summary statistics for estimated salinity calculated from the base case water budget. (Source: Appendix A, ECT 2008, revised Sept. 2008)

Subarea	Average	Standard Deviation	Maximum	Minimum
Snake Creek/ Oleta River	31.5 4.0		36.6	20.1
North 32.	4	2.3	36.4	26.6
Miami River	33.2	1.9	36.6	28.8
North Central	33.5	2.7	38.6	21.8
South Central - Inshore	32.7 3.6		39.6	18.4
South Central - Mid-bay	35.2 2.2		40.3	28.0
South – Card Sound	33.3	3.1	39.8	22.6
South - Barnes Sound	30.2 5.3		42.4	13.8
Region				
North 32.	4	3.0	36.6	20.1
Central 33.	8	3.1	40.3	18.4
South 31.	8	4.6	42.4	13.8

Sensitivity of Salinity to Inflow

Statistical analyses were conducted on the mass balance model results to provide insights on the degree to which changes in the management of major water sources (e.g., canal flows, groundwater flows, overland flows) would affect salinity conditions (**Appendix A**). The assumptions used for these analyses are summarized in Table 3.3 of **Appendix A**. Salinity was judged to be affected by either inflow components or rainfall if the corresponding coefficient in the linear model test was significantly different from zero at the p=0.05 level (**Figures 11** through **13**). The analyses show that the system is most sensitive to groundwater inputs under conditions resulting in high salinity (**Figure 11**), whereas, under conditions resulting in low salinity, (**Figure 12**) the system is most sensitive to canal flow. Specific to low flow conditions, the analyses show that on an overall watershed basis, annual maximum salinity is sensitive to annual total watershed inputs in four of the eight subareas of Biscayne Bay (**Figure 13**). These include the North area and Miami River, and Card Sound and Barnes Sound (lagged by one year). When the inflow sources are considered individually, there are six subareas in which annual maximum salinity is sensitive to annual groundwater inflow, two sensitive to wetland inflow (Central Inshore and Mid-bay), and one that is sensitive to canal flow (North). The results shown in **Figure 11** suggest that the influence of both low groundwater and low wetland flow into the nearshore extends into the adjacent Mid-bay in the Central region.

A field-based study of groundwater flow using seepage meters and geochemical methods confirms groundwater flow into Biscayne Bay and spatially shows where discharge occurs (Stalker, Price, and Swart 2007). The results of this work indicate a brackish groundwater discharge on the entire western shoreline and up to 1 kilometer eastward from the shoreline. The overall extent northward and eastward of lower salinity water was larger in the wet season than in the dry. The lowest surface salinity values were observed in the northwestern portion of the bay, while the lowest sediment/water interface salinities were observed in the southwestern portion of central Biscayne Bay (near Turkey Point). A regression analyses indicates that the nearshore sites receive the highest proportion of groundwater. This discharge is found in both wet and dry seasons as far south as Turkey Point, which is contrary to previous work. Overall, these researchers report: groundwater represents 10 percent of the total fresh water entering Biscayne Bay in the dry season and 14 percent in the wet season. Other sources of fresh water include direct rainfall and canal flows.

The combination of the mass balance analyses and the fieldwork indicates that under low flow, groundwater is an important consideration and impacts salinity conditions, whereas under high flow, the canal flow becomes dominant. Further analyses would need to be performed to establish a link between stage or canal level within specific locations in the watershed and salinity within the bay.

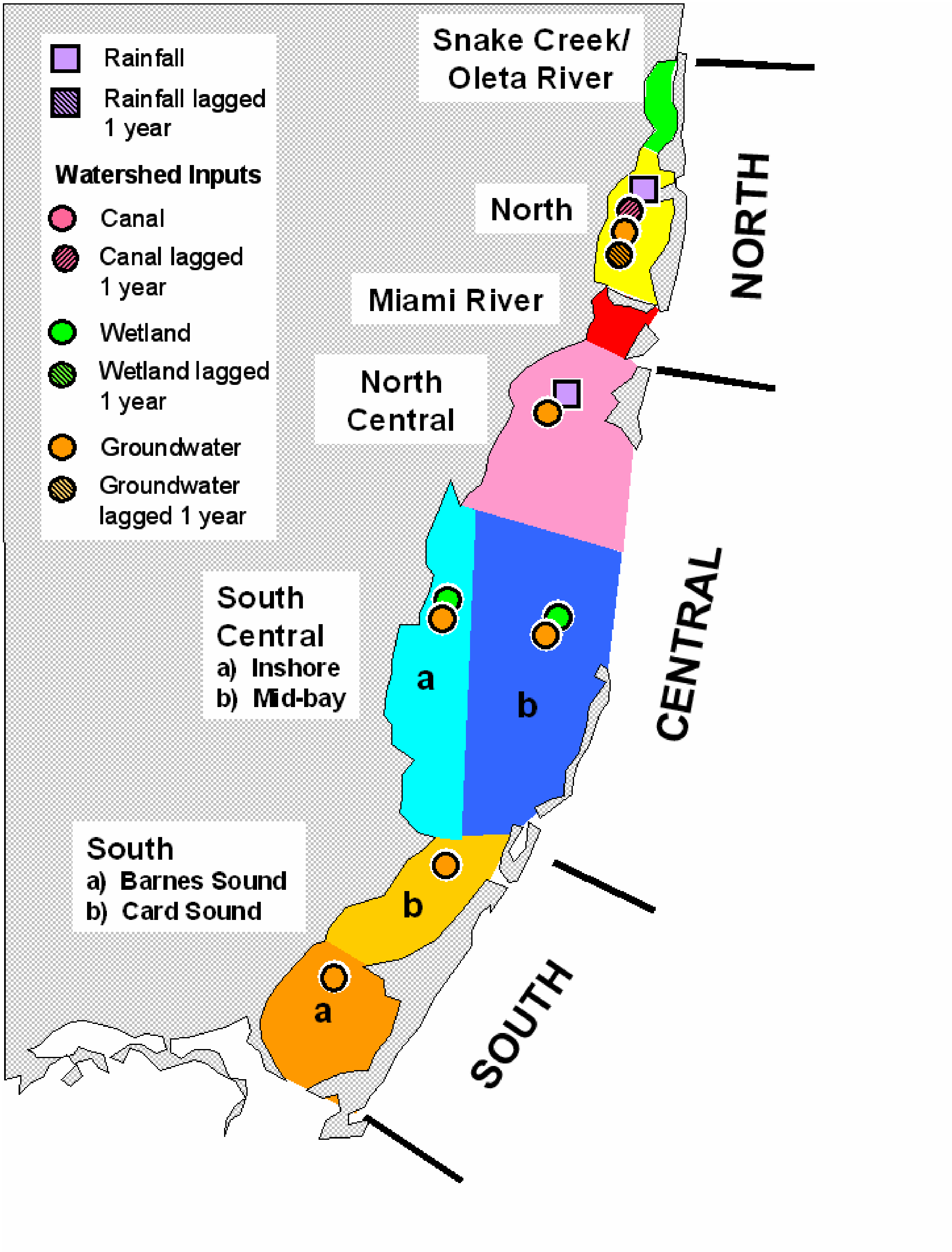


Figure 11. Subareas in which annual MAXIMUM salinity is sensitive to annual total canal inflow, ungauged wetland inflow, groundwater inflow, or rainfall in current or preceding years. The colors assigned to each subarea are the same as in Figure 9. (Source: Appendix A, ECT 2008, revised Sept. 2008)

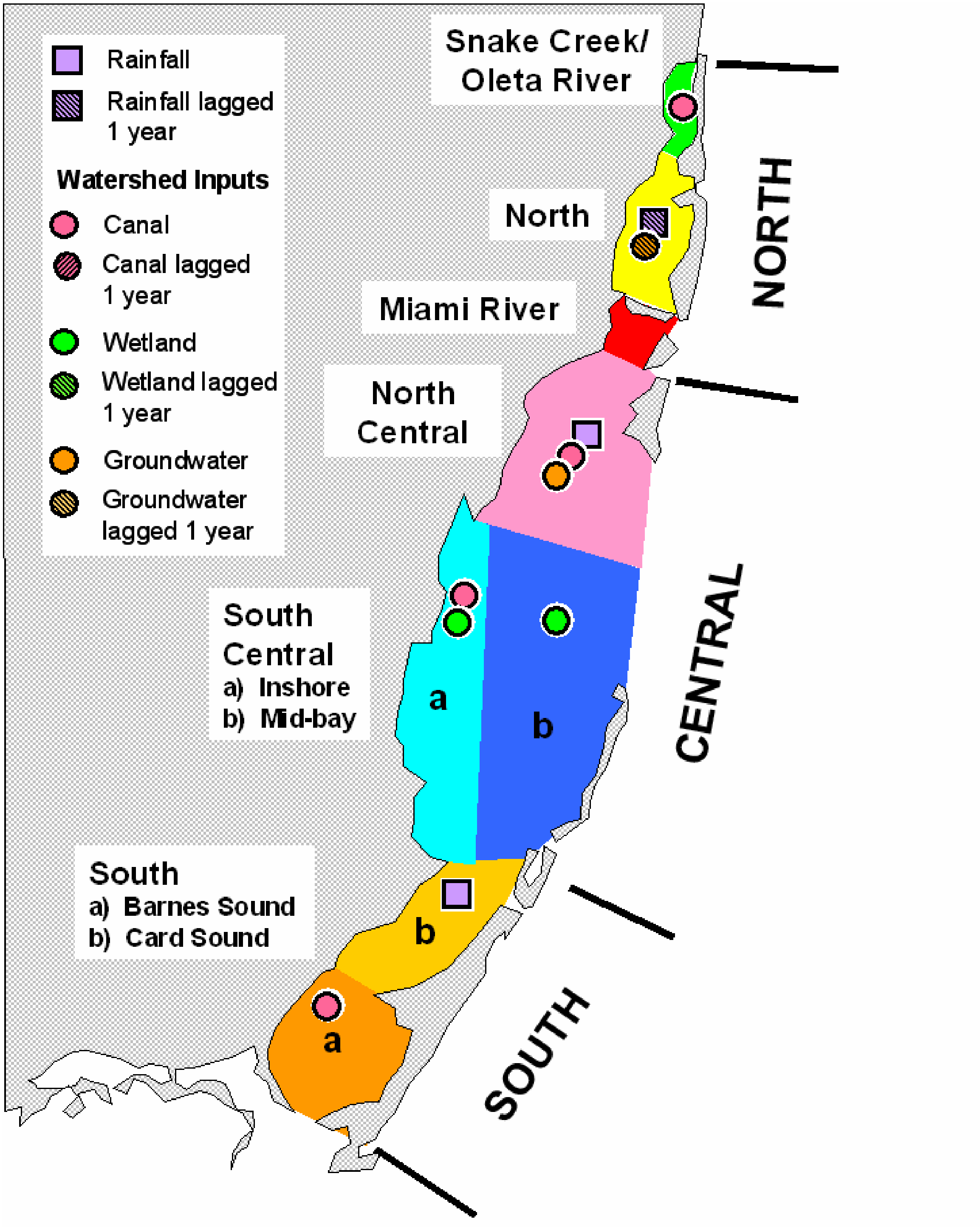


Figure 12. Subareas in which annual MINIMUM salinity is sensitive to annual total canal inflow, ungauged wetland inflow, groundwater inflow, or rainfall in current or preceding years. The colors assigned to each subarea are the same as in Figure 9. (Source: Appendix A, ECT 2008, revised Sept. 2008)

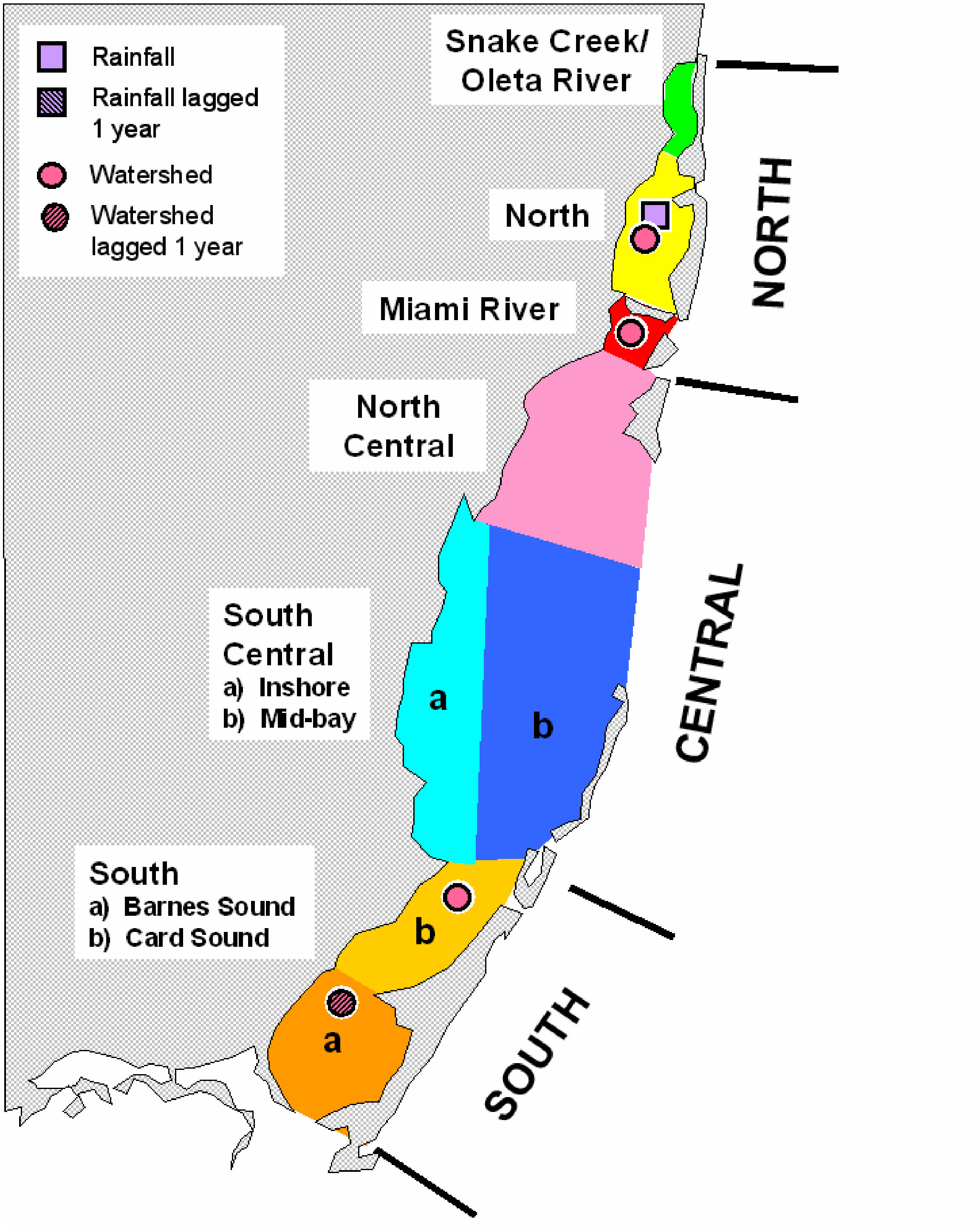


Figure 13. Subareas in which annual MAXIMUM salinity is sensitive to annual total watershed inputs or rainfall in current or preceding years. The colors assigned to each subarea are the same as in Figure 9. (Source: Appendix A, ECT 2008, revised Sept. 2008)

Historic Salinity Patterns

Several paleoecologic studies have been undertaken within the Central and South regions of Biscayne Bay. Most work has focused on reconstructing historic patterns of salinity from paleoecologic data within sediment cores and deriving influx of fresh water based on occurrences of species found in the cores and their salinity tolerances. This is consistent with a recent field study (Stalker, Price, and Swart 2007) and the results of mass balance modeling (**Appendix A**).

Wingard *et al.* (2004) compiled information and analyses of cores collected in 2002 and 2003 with cores from 1996 and 1997 in the Central and South regions of Biscayne Bay. The researchers concluded that a general trend of increasing salinity in the 20th century was indicated in the Central and South regions of the bay. Two nearshore sites in the Central region showed increases in average salinity accompanied by an increase in variability in the 20th century. This is consistent with increased magnitude of flow in the wet season and decreased flows in the dry season. Interestingly, the authors also suggest that nearshore sites in very close proximity to each other have been historically affected by localized hydrologic regimes and note that some proposed salinity targets for nearshore wetlands may not reflect historic conditions at those specific sites. Central bay sites located on mud banks away from the nearshore area indicate polyhaline to euhaline salinities over the past three to four centuries with increases in continental shelf and open marine influence in the 20th century. Corings from Card Sound indicate large swings in salinity over multi-decadal and centennial time scales. However, during the latter part of the 20th century, the site has been more marine influenced and salinity variations have decreased. The record from Middle Key Basin (Wingard *et al.* 2004) and Manatee (Ishman *et al.* 1998) indicates a steady increase in salinity that began before 1900 with a freshwater environment evident at the base of the cores and estuarine at the top.

Wingard *et al.* (2004) concluded from analyses that the 20th century salinity changes resulted from several factors, including 1) rising sea level; 2) changes in either surface or groundwater flows into the bay; 3) changes in average rainfall or rates of evaporation; 4) changes in sedimentation rates; and 5) a combination of factors. The timing at the nearshore sites suggest that both anthropogenic and natural causes are involved and the authors conclude that Biscayne Bay appears to be evolving into a more marine type system due to both causes.

WATER QUALITY TRENDS

Minimum inflow evaluations do not directly address water quality and a detailed water quality discussion was outside the scope of this report. It is recognized that regulatory inflow criteria that provide specification only for inflow quantity do not ensure that a resource is fully protected. Many aspects of water quality directly or indirectly impact the health and distribution of the biological resources. An example is a negative impact on submerged vegetation that may be introduced due to reduced water clarity with increased freshwater inflow (Hunt 2008; Hunt and Doering 2005).

A number of potential sources of both groundwater and surface water contaminants in the terrestrial areas adjacent to Biscayne Bay could enter Biscayne Bay and influence the biological resources. Although pollutants could potentially enter the bay under normal conditions, the greatest concern would be during periods of high flow.

Routine water quality monitoring was initiated in Biscayne Bay by Metro-Dade County's Department of Environmental Resources Management beginning in 1979 (SFWMD 1995). A water quality study (Caccia and Boyer 2005) found that the spatial distribution of water quality in Biscayne Bay is related to land use and associated terrestrial runoff entering canals, which then drain into the bay. Deeply dredged rock mines, lakes, and water storage sites collect and hold urban runoff. The highly permeable limestone of the region makes the groundwater susceptible to the infiltration and spread of nonpoint source pollutants from surface water runoff and dredged sites (Wolfert-Lohmann *et al.* 2008). Activities that re-establish groundwater into offshore springs in Biscayne Bay are cause for some concern. These activities could create the potential for flushing stagnant and possibly contaminated groundwater into the offshore marine ecosystem, which could degrade habitats within the bay (Wolfert-Lohmann *et al.* 2008).

Within Biscayne Bay, there are numerous marinas and the heavy vessel use has resulted in numerous impacts to the bay, such as sewage releases, solid wastes, fuel and oil pollution, metal accumulation, and propeller scouring in seagrass beds.

SUMMARY OF HYDROLOGIC CONDITIONS

The watershed and hydrology are summarized as follows:

- The watershed is highly urbanized and Biscayne Bay has experienced considerable change due to extensive regional population growth with substantial coastal and watershed development.
- During the past century, the hydrology of south Florida has been highly modified for agricultural, urban, and commercial development, including recreational use. Changes made to provide drainage and flood protection for cities, homes, and farms, and to provide water for irrigation, recreation, and commercial use have altered the structure and function of the coastal tidal creeks and wetlands within the watershed that once provided a hydrologic connection to Biscayne Bay.
- These activities have reduced the capacity to store excess rainfall during the wet season for slow release to the bay during dry periods.
- The inland movement of salt water is a major resource concern in the coastal areas of Miami-Dade County.
- Sea level in south Florida has risen at least 7.9 inches (20 centimeters) over the past 100 years (Wanless, Parkinson, and Tedesco 1994) and this change has likely affected the salinity regime of Biscayne Bay (Wingard *et al.* 2004).
- Recent hydrologic analyses quantify the relationship between freshwater flow and salinity throughout the bay and indicate regional differences in inflows. The water budget shows that both groundwater and canal inflow are relatively important components on a volume basis in the Central region (i.e., subareas, including North Central and South Central). The total inflow in the South region (i.e., subareas, including Barnes Sound and Card Sound) is small relative to the other regions and is dominated by a combination of overland and groundwater inflow. Canal flow dominates in the North region and there is virtually no overland flow. Comparison of the water budgets for wet, dry, and normal years reinforces and expands the regional differences.
- The relative influence of canal inflows in the water budget is different by subarea and region. The North region is relatively well flushed and has a low freshwater displacement, whereas the South region is not well flushed and has a high freshwater displacement.

- Regional differences are evident in salinity patterns. Both salinity observations and the results of the basin salinity time series produced from the base case water budget indicate the potential for hypersalinity to occur, particularly in the Central and South regions.
- All areas of the bay are sensitive to inflow quantity. The statistical analysis presented show that the system is most sensitive to groundwater inputs under conditions resulting in high salinity (**Figure 11**), whereas, under conditions resulting in low salinity, (**Figure 12**) the system is most sensitive to canal flow. When the inflow sources are considered individually, there are six subareas in which annual maximum salinity is sensitive to annual groundwater inflow (in the North, Central, and South), two sensitive to wetland inflow (Central Inshore and Mid-bay), and one that is sensitive to canal flow (North).
- The combination of the mass balance analyses and the fieldwork indicates that under low flow, groundwater is an important consideration and impacts salinity conditions, whereas under high flow, the canal flow becomes dominant.
- There are water quality concerns with increasing the volume of water to Biscayne Bay.

3

Biological Resources

BACKGROUND

The development of inflow criteria in coastal ecosystems typically requires establishing a link between inflow, salinity, and biological resources. Specific goals of the biological resource evaluations (i.e., levels of protection) are determined by the type of inflow tool being considered. For example, the overall goal of a MFL evaluation is to define a flow or level needed to protect living resources from significant harm. This level of protection often involves defining a threshold survival salinity for a community or valued ecosystem component (VEC). In contrast, the goal of a water reservation evaluation is to define the inflow that protects fish and wildlife to ensure a healthy and sustainable habitat for fish and wildlife communities that can remain healthy through cycles of drought, flood, and population variation. Thus, the level of protection varies between regulatory tools, and evaluations may involve establishing different resource and salinity links. The following information summarizes the biological resources of Biscayne Bay and surveys known salinity thresholds for the resources to establish potential VECs or biological indicators that are consistent with the definition of MFL criteria. This is due to the availability of technical evaluations done in the MFL context. Although the summary information would be useful in the context of an overall inflow evaluation, a separate evaluation would need to be done to establish a link for a water reservation evaluation that is consistent with the specific protection goals.

Identifying and selecting the VEC or biological indicator is a key step used in the District's resource-based approach for developing regulatory criteria. The VEC is defined as a component in an ecosystem that is considered important by members of the public, scientists, and government involved in assessing the environmental impact of a proposed project or management action. Importance may be determined based on scientific concerns or cultural values. This approach assumes that providing environmental conditions suitable for the VEC will also provide suitable conditions for other desired species or habitat present within the ecosystem. This approach is similar to the methods outlined by the U.S. Environmental Protection Agency Estuary Program (USEPA 1987). In general, VECs selected for establishment of a MFL represent those that are critical for sustaining the ecosystem and are found to be sensitive to the effects of a consumptive use withdrawal. This chapter provides an overview of the biological resources present within Biscayne Bay, including candidate VECs considered in this process.

The biological resources of the three regions within Biscayne Bay – North, Central, and South (**Figure 3**) are summarized in sections within this chapter. Each section includes a description of dominant organisms, habitats, and known salinity tolerances of key organisms within each region. These sections also review habitats and biological resources in the transition zone or land adjacent to the open waters within each region of the bay. Conceptual ecological models are also reviewed.

CONCEPTUAL ECOLOGICAL MODELS FOR BISCAYNE BAY

A conceptual ecological model for the Biscayne Bay ecosystem has been developed as part of the Everglades Restoration Program (Browder *et al.* 2005). This model is considered a qualitative planning tool that identifies major anthropogenic drivers, stressors on the natural system and their ecological effects, and the biological indicators of responses (Ogden *et al.* 2005). It provides a framework for the system that is useful to describe the process for evaluating inflow criteria. The model for Biscayne Bay incorporates ecological variables within the bay, coastal habitats, and freshwater sources. The adjacent coastal wetland communities, including herbaceous marshes and coastal mangrove wetlands, are recognized as being functionally connected to the bay and historically part of the estuarine ecosystem.

The three principal drivers in the model are watershed development, sea level rise, and water management. The stressors resulting from these drivers include toxicant and pathogen inputs, altered solids and nutrient inputs, altered freshwater flows, and operation of structures. The conceptual model focuses on the effect of water management drivers on operation of structures, and to some degree, altered freshwater flow. The effects of watershed development and sea level rise are also important.

Ecological attributes in this model include four primary types of habitat: mangrove forests, herbaceous wetlands, seagrass meadows, and benthic faunal communities (soft and hard bottom). The model also includes species level attributes, which have special relevance and use in monitoring and reporting, including pink shrimps (*Farfantepenaeus duorarum*); blue crabs (*Callinectes sapidus*); stone crabs (*Menippe mercenaria*); oysters (Ostreidae family); estuarine fish communities; fish and bottlenose dolphin (*Tursiops truncates*) health; crocodiles (*Crocodylus acutus*); West Indian manatees (*Trichechus manatus latirostris*); and wading birds. This model is shown in **Appendix J**: Conceptual Ecological Models.

In addition to models developed for Biscayne Bay, a conceptual model of a mangrove estuarine transition area has been developed within the context of the Everglades Restoration Program (Davis *et al.* 2004). This model encompasses a brackish water ecotone of coastal bays and lakes, mangrove forests, salt marshes, tidal creeks, and upland hammocks that separate Biscayne Bay, Florida Bay, and the Gulf of Mexico from the freshwater Everglades. 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 (*Mycteria americana*) and roseate spoonbill (*Platelea ajaja*), estuarine crocodile populations, and the structure and function of the mangrove forests and associated plant communities. This model is also presented in **Appendix J**: Conceptual Ecological Models.

MAJOR HABITATS AND BIOLOGICAL RESOURCES

The quality and extent of habitats contained within coastal ecosystems largely determine species composition and are thus a major consideration for inflow criteria development. In general, habitats provide physical substrate, food source, homes, and refuge for organisms. Additionally, they can dictate physical attributes, such as sediment stability or other water quality considerations, and can be an important part of the overall food web. Even species that do not directly reside in certain habitats may derive associated benefits from their presence. For example in coastal areas, birds find food sources in coastal wetland habitats, fish find food sources within submerged aquatic vegetation (SAV), manatees use SAV as a food source, and predators find food sources near reef habitats. Shallow nearshore SAV beds or mangrove habitats with reduced salinity may provide nursery habitat and refuge from larger euhaline predators.

The principal habitat types identified in the Biscayne Bay Conceptual Ecological Model (Browder *et al.* 2005) include:

- Herbaceous wetlands
- Mangroves
- Seagrass meadows
- Benthic faunal communities

Herbaceous wetlands: Coastal wetlands are highly productive habitats that provide nursery, foraging, and refuge areas for birds, fish, and invertebrates. In addition, coastal wetlands help maintain water quality by filtering sediments and nutrients from inflowing waters. In a lagoonal estuary, the wetland/tidal creek ecosystem naturally provides the hydrologic connection between the land and sea. These areas, or “transition zones,” typically contain a series of ponds and wetlands, and connect to the coast via numerous tidal creeks that create an estuarine environment by maintaining a salinity gradient from the freshwater to saltwater environment over a fairly large area. An example is the transition zone of neighboring Florida Bay (SFWMD 2006). In all areas of Biscayne Bay, the connection of the bay to the freshwater wetlands has been highly altered due to urbanization, development, and hydrologic alterations within the watershed over the past 100 years (see **Chapter 2**) and much of their ecological function has been lost.

The North region of Biscayne Bay is highly urbanized and no longer sustains natural wetland areas. Remaining wetland communities in the south and central Biscayne Bay watershed consist primarily of two types: the saline intruded, primarily mangrove-dominated zone east of the L-31E, and the exotic-dominated freshwater wetlands west of L-31E. These two wetland systems are not currently connected by overland flow to the bay; however, a groundwater connection is assumed to be important. The freshwater wetlands offer very limited storage, retention, and infiltration sites for groundwater flows. Both surface water and groundwater sources are used in this watershed for potable (urban) water supply and irrigation of landscape and agricultural crops. As agricultural and urban development continues, the volume, duration, and frequency of floodwaters may increase. The existing infrastructure of drainage systems is not intended to completely eliminate flooding in developed areas. Natural and undeveloped areas in the watershed provide flood control by providing areas for storage and infiltration of runoff, as well as a mechanism for moving floodwaters away from developed areas.

West of L-31E in the watershed, there are undeveloped lands that are marginal, rather limited, and discontinuous – found to be unsuitable for agriculture. Most of these lands were once cleared of native vegetation, ditched or drained for agriculture, and are now infested with exotic species. Agricultural and urban lands to the west provide sources of excess nutrients, pollutants, and contaminants that may adversely impact downstream resources. The undeveloped lands provide a limited, but important source of clean fresh water to the estuary by providing soil stabilization, low pollution loading, reduction of pollutants from runoff, and buffer from urban land uses.

Mangroves: Mangroves dominate the shoreline from Matheson Hammock south along the mainland and along most of the Biscayne National Park shoreline, Card Sound, and Barnes Sound. Four species of trees are considered mangroves in south Florida: red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), black mangrove (*Avicennia germinans*), and buttonwood (*Conocarpus erecta*). Mangrove communities are essential contributors to the bay systems. Coastal mangroves protect the shoreline from severe storm erosion. The extensive prop root systems dissipate wave energy, reduce tidal currents, and promote deposition of suspended sediment. Prop roots also provide protection for juvenile fish and attachment surfaces for marine organisms. Export of mangrove detritus is important to the continued functioning of coastal ecosystems. Fragments of marine grasses and mangrove leaves are consumed by bacteria, fungi, and protozoa, and are the food source of crustaceans (e.g., amphipods, mysids, copepods, and shrimps) and small or juvenile fish species. Detritus feeders are eaten by carnivorous worms, snails, and numerous juvenile fish, which, in turn, are eaten by larger predators, such as snappers, barracuda, sharks, and various birds. Mangrove communities are sensitive to alterations in drainage patterns, tidal inundation, overland runoff, and water quality. Changes in any of these factors may result in alterations in rates of leaf fall, changes in species distributions, increased tree mortality, or changes in the rates and kinds of material exported to the aquatic environment. Over time, these alterations can have a significant impact on adjacent bays. In most areas of Biscayne Bay, only a mangrove fringe area remains and represents a compressed estuarine zone that once encompassed a larger mangrove area, as well as wetlands and tidal creeks. The presence of the mangrove shoreline in Biscayne Bay is critical to preserving and maintaining current ecosystem function.

Seagrasses: Seagrass meadows may be found in shallow areas where light can penetrate the bottom. Their value as habitat is well documented – they provide structure, sediment stability, refuge, food sources, and are an important part of a complex food web. Seagrass beds provide abundant food and refuge, which are essential characteristics of a nursery area (Virnstein 1987).

Seagrass meadows provide habitat for many benthic and pelagic organisms, such as invertebrates and fish (Thayer, Kenworthy, and Fonseca 1984). They increase benthic primary productivity and stabilize sediments (Stoner 1983; Virnstein *et al.* 1983, Gilmore 1987; Fonseca and Fisher 1986; Woodward-Clyde 1998). Seagrass meadows also provide food sources for trophically and commercially important organisms (Dawes, Hanisak, and Kenworthy 1995) and can form the basis of detrital food chains (Zieman and Zieman 1989).

An important habitat within the bay is provided by submerged aquatic vegetation (SAV), which grows in beds wherever conditions are favorable. *Thalassia testudinum* (turtle grass) is the dominate species, although other species, such as *Halodule wrightii* (shoal grass) are also widely distributed. Some species, however, such as Johnson's seagrass (*Halophila johnsonii*) are restricted in spatial distribution. In Biscayne Bay, seagrasses cover much of the bottom and provide the basis for substantial commercial and recreational fisheries in the bay and neighboring waters (**Figures 14** through **17**). Seagrasses provide a food source and habitat for small fish and invertebrates that live in the grass beds. Larger sport fish, commercial species, and birds rely on the seasonal abundance of these small fish and invertebrates for successful growth and reproduction. Species considered commercially valuable in Biscayne Bay include snappers, mullets, sardines, baitfish, blue crabs, stone crabs, spiny lobsters, and pink shrimps. The commercial landings of fish and shellfish caught in Biscayne Bay, including Barnes and Card Sound, have risen significantly since 1995, due primarily to the growth in blue crab (*Callinectes sapidus*) and pink shrimp (*Farfantepenaeus duorarum*) harvests (Ault *et al.* 2001). Shellfish consistently account for over 90 percent of total landings by weight in recent years.

Output, income, and employment from commercial fishing reached its historical peak in 2000 with 141 jobs, $5.3 million in output value, and $3.9 million in income value (Hazen and Sawyer 2005). The specific commercial value of lifecycle-dependent species to the bay is difficult to pinpoint. Numerous reef species rely on Florida Bay, as well as Biscayne Bay, and other species are migratory. Species caught outside of the bay may be landed in places other than Miami-Dade County. The value of these species, caught inside and outside of the bay and landed in Miami-Dade County, achieved a value of slightly over $8.6 million in 1993 (Hazen and Sawyer 2005). The loss or degradation of Biscayne Bay habitat would have a significant effect on the local economy.

Benthic faunal communities: Benthic faunal communities comprise both soft and hard bottom areas. Benthic communities, such as mollusks, attached fauna, and infauna provide important ecological and biological functions within the bay and can influence the quality of the environment (Browder *et al.* 2005). Hard bottom species are an indicator of a stable salinity environment because they have low tolerance for salinity variation or high sediment loads. High sediment loads tend to smother new recruits, so they occur in areas that have exposed rock and/or less than 6 inches of sediment. Hard bottom communities consist primarily of sponges, alcyonarians, and various inshore corals (**Figures 14** through **17**).

The hard bottom and associated community of Biscayne Bay is part of the third largest reef in the world and at least 50 different species of coral can be found within Biscayne Bay. The dense hard bottom community characteristically has a greater diversity of soft corals, including a variety of large, attractive sea fans, sea whips, and related forms. Due to their size (up to 1 meter) and density, these dense assemblages of soft corals and sponges provide an excellent refuge for fish and various kinds of invertebrates, including shrimps, crabs, worms, brittle stars, sea urchins, and other species that live in holes and crevices. The most common sponges in the hard bottom community are the loggerhead sponge (*Spheciospongia vesparia*) and basket sponge (*Ircinia campana*). Numerous commercial sponge species also occur in this community in the Central and South regions of the bay. These include the sheepswool (*Hippiospongia lachne*), yellow sponge (*Spongia barbara*), grass sponge (*S. germinea*), and glove sponge (*S. cheiris*). Hard corals occasionally found within this community include finger coral (*Porites* sp.), star coral (*Solenastrea* sp.), and starlet coral (*Siderasterea* sp.). In addition, fire coral (*Millepora* sp.) is typically present. Oysters (*Crassostrea virginica*) are very limited in the Central and South regions, but have been observed in the North region near the mouth of Snake Creek.

Other Communities: Water column communities are also vital to the overall ecology of aquatic systems. Plankton are free-floating organisms that drift in the water column. Both planktonic plants (phytoplankton) and animals (zooplankton) play significant roles in the food web of Biscayne Bay. Phytoplankton are important as a basis of the aquatic food chain. The most important phytoplankton in coastal waters are diatoms and dinoflagellates. These microscopic algae provide food for numerous types of zooplankton, including the larvae of many bottom-dwelling (benthic), free-swimming (neritic), and open water (pelagic) animals.

Phytoplankton surveys (Brand 1988) showed uniformly low levels of phytoplankton biomass in the South region of the bay, which are much lower in comparison to typical estuaries in the United States. The dominant phytoplankton throughout the bay belongs to the Coccoid class. The limiting nutrient for phytoplankton growth in Biscayne Bay is phosphorus. Zooplankton includes many types of free-floating animals, ranging from microscopic protozoans to very large forms, such as jellyfish. Zooplankton also includes the larvae and early juvenile stages of most species of mollusks (e.g., clams, oysters, and various shellfish), decapod crustaceans (e.g., shrimps and crabs), and fish. In the nearshore zone of the Central region of the bay, zooplankton biomass is greatest; decreasing offshore (Roman, Reeve, and Froggart 1983). Total numbers of fish eggs and larvae are greatest in the spring and summer, coinciding with seasons of high phytoplankton and zooplankton abundance (Houde and Lovdal 1985).

Fish: The mangrove and estuarine areas support a diverse collection of littoral, mangrove, and estuarine fish. Near fresh water inputs in some areas of the bay, species more typical of an estuarine environment can be found, including pink shrimp (*Farfantepenaeus duorarum*), blue crab, (*Callinectes sapidus*), and mullet (Mugilidae family). Several important game and food fish are strongly associated with these environments (**Table 8**). Additionally, juvenile reef fish, such as the blue striped grunt (*Haemulon sciurus*) and gray snapper (*Lutjanus griseus*), are known to occupy shallow the nearshore mangrove and seagrass habitats and illustrate the importance of the ecological connectivity between coastal and marine habitats (discussed in more detail in the Habitat Connectivity section). The live-bearing (Poeciliidae) and egg-laying (Cyprintodontidae) topminnow families are specialized for this habitat. The former is represented by two species of mosquitofish (*Gambusia* sp.) and sailfin mollie (*Poecilia latipinna*), while the latter contains six species of brackish water killifish (*Fundulus* sp.) that occur in the bay. Various gobies, blennies, eels, worm eels, and wormfish are also known to occur in this area. Two families of flatfish (Bothidae and Cynoglossidae), as well as barracuda (*Sphyraena barracuda*), invade brackish water in the bay. Bull sharks (*Carcharhinus leucas*) are quite tolerant of low salinities. These predators travel estuarine areas and mangrove creeks in Biscayne Bay. The sawfish (*Pristis* sp.) is also found in brackish areas. Seagrass bed and tidal flat habitat is prevalent in Biscayne Bay and the corresponding fish fauna is well developed. Many commercial and game fishes important to anglers in the bay area are dependent on seagrass beds (**Table 9**) (Voss *et al.* 1969).

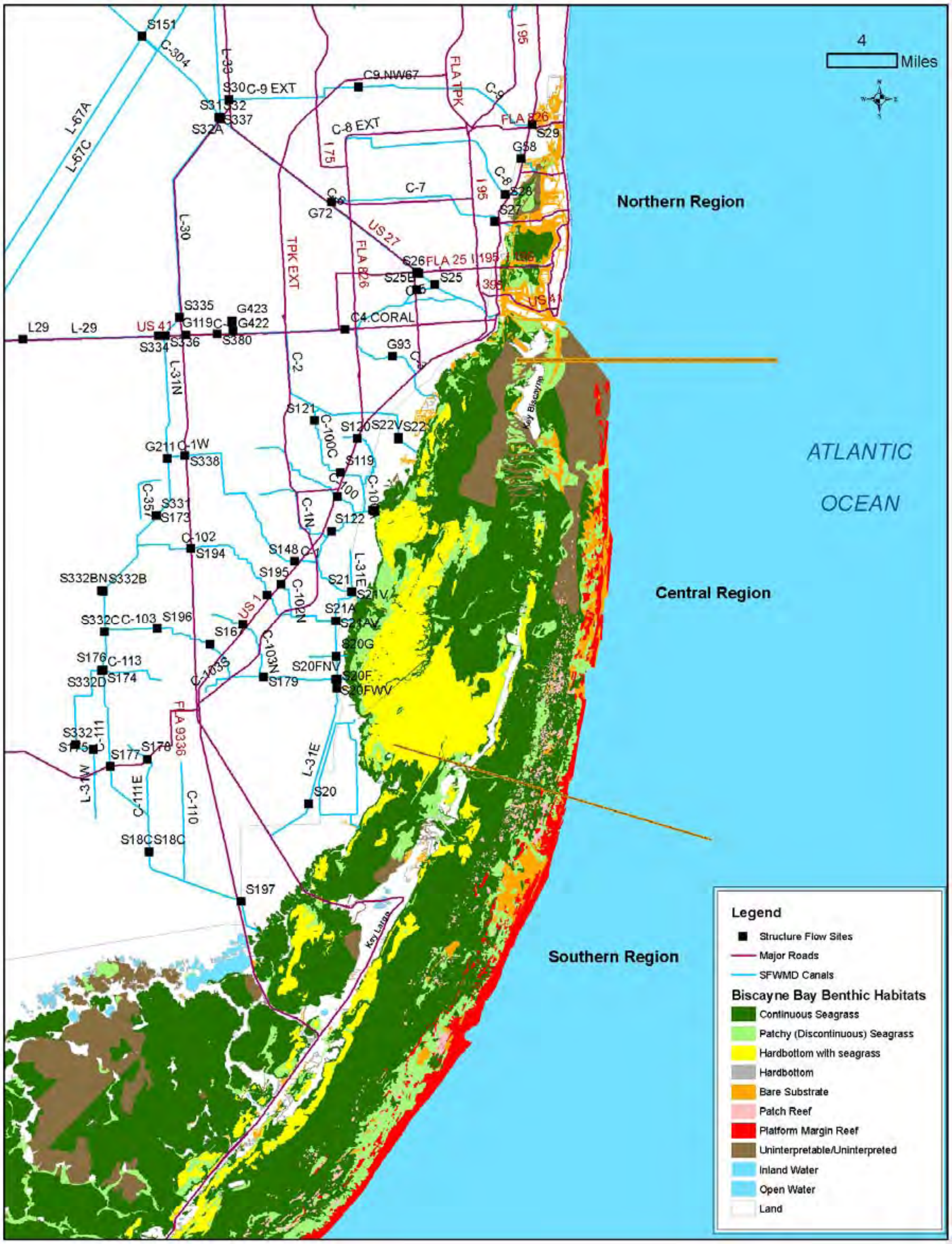


Figure 14. Biscayne Bay benthic habitats. (Source: SFWMD 2008)

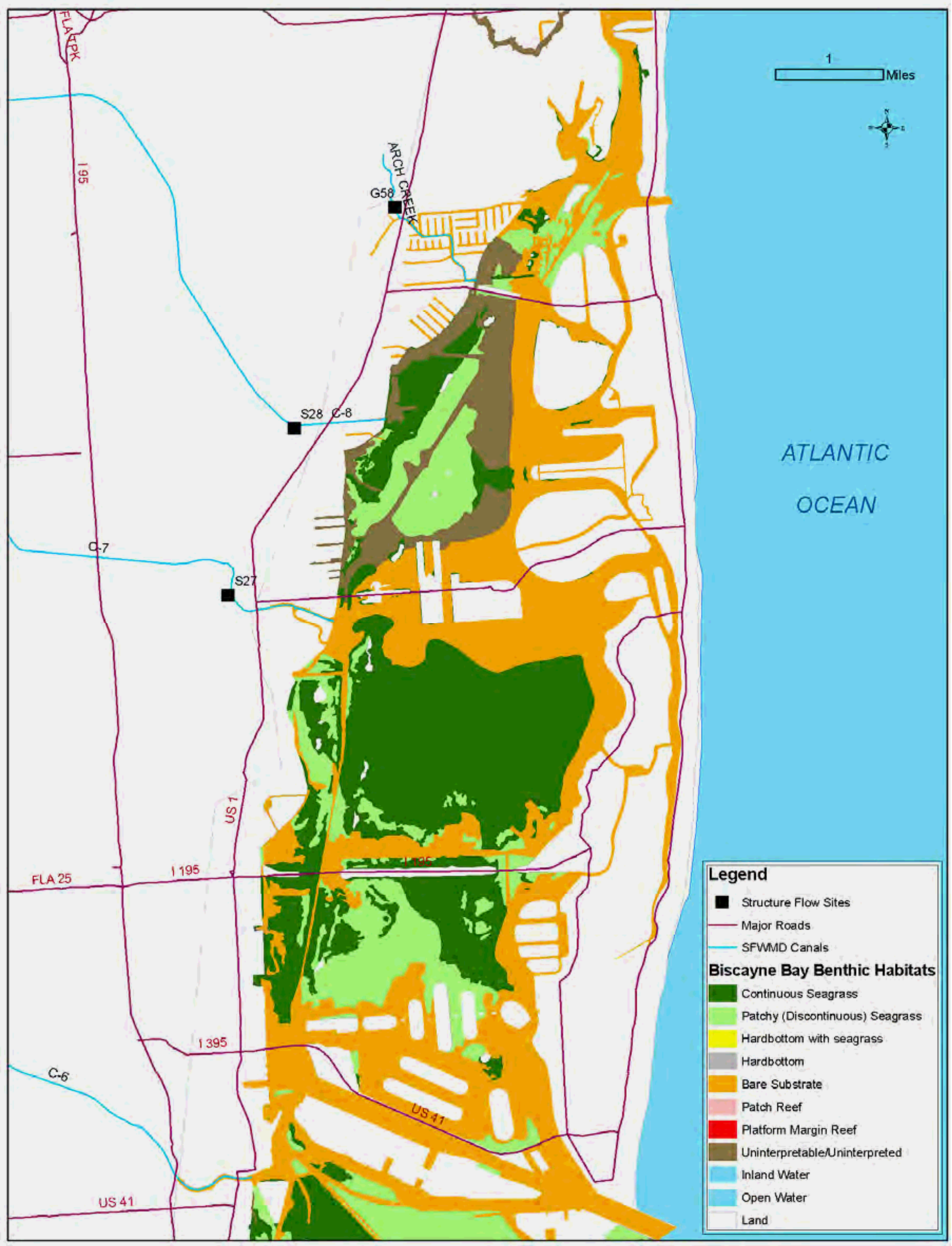


Figure 15. North region of Biscayne Bay benthic habitats. (Source: SFWMD 2008)

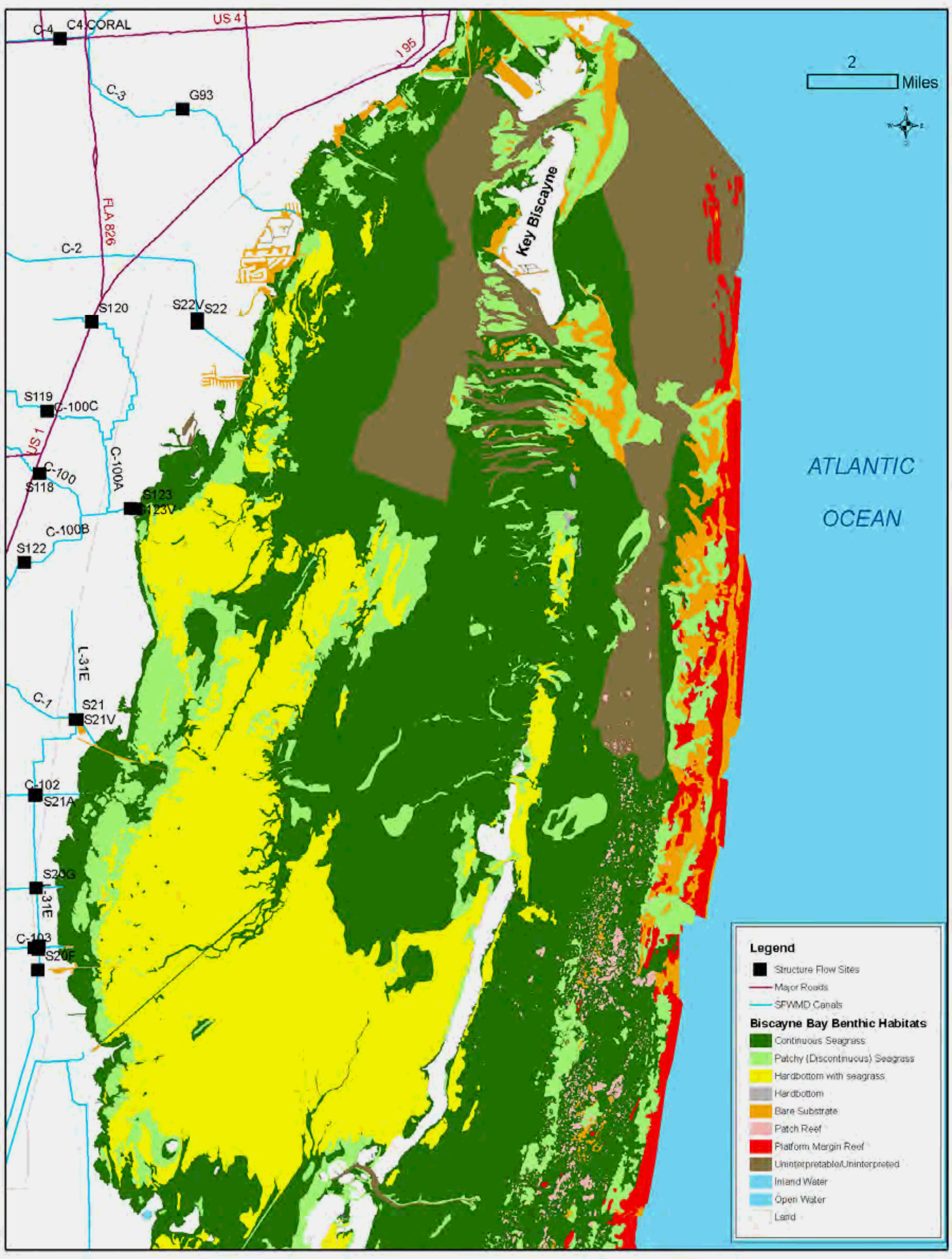


Figure 16. Central region of Biscayne Bay benthic habitats. (Source: SFWMD 2008)

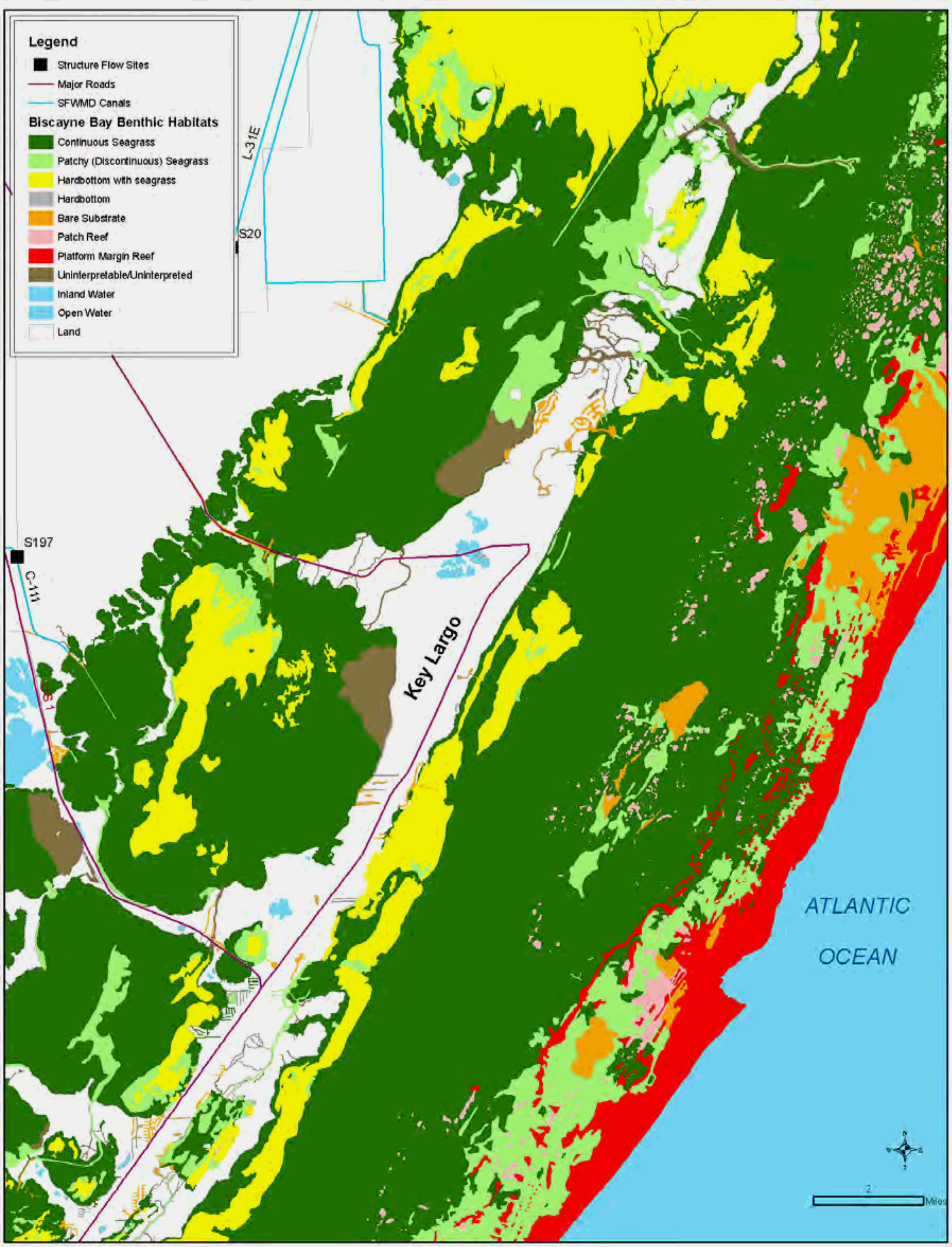


Figure 17. South region of Biscayne Bay benthic habitat. (Source: SFWMD 2008)

Table 8. Fish associated with littoral, mangrove, and estuarine habitat in Biscayne Bay. (Source: SFWMD 1995)

Common Name	Scientific Name
Common snook	*Centropomus undecimalis*
Red drum or Redfish	*Sciaenops ocellata*
Spotted seatrout	*Cynoscion nebulosus*
Silver perch	*Bairdiella chrysoura*
Sheepshead	*Archosargus probatocephalus*
Tarpon	*Megalops atlantica*
Gray snapper	*Lutjanus griseus*
Jack (several species)	*Caranyx hippos, C.* sp.
Mojarra (several species)	*Gerres* sp.
Mullet (several species)	*Mugil* sp.

Table 9. Recreationally important fish species dependent on seagrass bed habitat in Biscayne Bay. (Source: Voss *et al.* 1969)

Common Name	Scientific Name
Bonefish	*Albula vulpes*
Ladyfish	*Elops saurus*
Pompano	*Trachinotus carolinus*
Permit	*T. fulcatus*
Red drum	*Sciaenops ocellata*
Spotted seatrout	*Cynoscion nebulosus*
Silver perch	*Bairdiella batabana*
Hogfish	*Lachnolaimus bifasciatum*
Nassau grouper	*Epinephelus striatus*
Red grouper	*E. adscensionis*
Black grouper	*Mycteroperca bonaci*
Gag grouper	*M. microlepis*
Yellowfin mojarra	*Gerres cinereus*
Jack Crevalle	*Caranyx hippos*

Seagrass beds in Biscayne Bay also serve as important habitat for a variety of species, including sea horses and pipefish (14 species of the Syngnathidae family); eels (Congridae, Ophidiidae, and Muraenidae families); gobies (Gobiidae family); blennies (Clinidae family); puffers (Tetraodontidae family); cowfish and trunkfish (*Lactophrys* sp.); wrasses (Labridae family); big-mouthed toadfish (*Opsanus tau*), midshipman (*Porichthys porosissimus*) and parrotfish (Scaridae family). Although less well known, bottom-dwelling dragonets (*Callionymus* sp.), sea robins (Triglidae family), and batfish (*Ogcocephalus* sp.) are also present. Several species of scorpionfish (Scorpaenidae family) inhabit the seagrass beds disguised as rocks covered with marine growth to stalk prey. Two fish species found in the bay, conchfish (*Astrapogon stellatus*) and pearlfish (*Carapus bermudensis*), are uniquely able to seek refuge inside invertebrates that live within seagrass beds. Jawfish

(Opisthognathidae family) are situated within permanent burrows among the seagrass beds, while many eel species (Ophichthidae family*)* burrow under substrate. Snappers (Lutjanidae family) and grunts (Pomadasyadae family) are often sheltered by coral, but forage among the seagrass beds. Several shark species, particularly lemon (*Negaprion brevirostrus*), blacknose (*Carcharhinus acronotus*), sharpnose (*Rhizopriodon terraenovae*), and bonnethead (*Sphyrna tiburo*), regularly use the seagrass beds.

Reef fish move nocturnally to forage on seagrass beds. These species are usually found in the hard bottom communities associated with sponges, alcyonarians, and shallow water corals. A trawl survey inside the bay found a variety of angelfish, butterflyfish, damselfish, surgeonfish, cardinalfish, squirrelfish, bigeye, green moray, and numerous other species that are more typical of Caribbean reefs than of bays (Berkeley 1984). Because of seawater flushing, salinity tends to be relatively high in the eastern half of the bay, and water quality is apparently suitable for reef fish. The fishes associated with sponges and alcyonarians in the hard bottom communities of Biscayne Bay are not as important to anglers or as diverse as those in the seagrass beds. However, they include some of the most striking fish found in the bay, and occur where corals are most likely to be encountered inside the bay. In addition, a few specialized fishes are characteristic of this habitat, including five species of anglerfish or frogfish (*Antennarius* sp.), which can swallow prey as large as themselves; the orange filefish (*Aluteria scripta*), which feeds on various marine growth; and the lined seahorse (*Hippocampus erectus*), which holds onto alcyonarians with its prehensile tail while seeking small prey.

Some fish live in the open water of Biscayne Bay, irrespective of the bottom type. One key group is the small, schooling planktonic eaters, such as silversides (Atherinopsidae family), sardines and herrings (Clupeidae family), and anchovies (Engraulidae family). These numerous fish are an important link in the food chain, serving as prey for various fish and other animals (e.g., least tern). Other open water fish in the bay are predators, including several species of needlefish (Belonidae family) and barracuda and its relatives (Sphyraenidae family).

Turtles: The distribution of sea turtles within Biscayne Bay, the coastal islands, and the southern sounds is not well documented. Historically, the turtle fishery was a major source of income and food for local settlers (deSylva 1976). Green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtles regularly forage within the bay. Leatherback (*Dermochelys coriacea*) and Kemp's Ridley (*Lepidochelys kempi*) sea turtles have been reported sporadically off the coast or as strandings, but do not regularly occur in the bay. Important habitats for chelonian species are seagrass beds, hard bottom communities, coastal wetlands, salt marshes, and barrier island nesting beaches. In the bay region, the predominantly vegetarian green turtle feeds in seagrass beds, whereas the diet of the more omnivorous loggerhead includes sponges, mollusks, crustaceans, sea urchins, and plants found in hard bottom communities. The smaller, fast-swimming hawksbill (*Eretmochelys imbricate*) has also been known to use seagrass beds (Voss *et al.* 1969).

Birds: Birds, such as roseate spoonbills, snowy egrets, herons, and woodstorks use the mangrove forest and wetland habitats for food sources and/or nesting. Birds that forage primarily in the open water of the bay while swimming submerged include cormorants (*Phalacrocorax* sp.), mergansers (*Mergus* sp., *Lophodytes* sp.), coots (*Fulica* sp.), and diving ducks (Aythyinae subfamily). Food sources for these birds include fish, invertebrates, plants, and animals. Birds that forage by plunging from flight to catch fish from the upper layer of surface waters include pelicans (*Pelecanus* sp.), ospreys (*Pandion haliaetus*), terns (Sterninae subfamily), and kingfishers (*Megaceryle alcyon*). The black skimmer (*Rynchops nigra*) catches small fish and macroinvertebrates with its highly specialized knife-like bill. Birds that primarily use airborne foraging strategies (picking up food over the bay or land) include bald eagles (*Haliaeetus leucocephalus*) and frigatebirds (*Fregata magnificens*). Gulls (*Larus* sp.) are ubiquitous in the bay and surrounding area. They forage by landing and swimming to food. Dabbling ducks (Anatinae subfamily) and coots forage for invertebrates and plants from swimming positions at the bay's surface.

Marine Mammals: Biscayne Bay provides foraging habitat for two species of marine mammals, the bottlenose dolphin (*Tursiops truncatus*) and the West Indian manatee (*Trichechus manatus*). These animals commonly occur in the bay or its tributaries. Both species are protected by the *Marine Mammal Protection Act of 1972*, which makes it illegal to take, injure, molest, or kill any marine mammal. The West Indian manatee is also listed as federally endangered by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act. The bottlenose dolphin is the common dolphin of inshore Florida waters, and normally forages in open waters of the bay, feeding on mullet and other available species of fish.

Manatees occur in open waters and tributaries of Biscayne Bay, but tend to congregate in protected channels and nearshore areas. Manatee habitat requirements include water at least 1 to 5 feet in depth; safe travel corridors to access dense vegetation for feeding; a supply of clean fresh water for drinking; and warm water during cold weather. The most heavily used areas in South Central Biscayne Bay include the Deering Bay Marina and Black Point Marina (Miami-Dade County DERM 1992). The latter area has been designated in the county's Manatee Protection Plan, and the manatee habitat in this area is generally limited to the lower reaches of Black Creek and the offshore channel (Miami-Dade County DERM 1992). A Florida Manatee Protection Plan has been developed by the USFWS. One of the plan's objectives is to establish minimum flows and levels to "ensure that resources of importance to manatees are minimally affected" (USFWS 2001).

Regional Differences

The varying physical characteristics within the different regions of Biscayne Bay, (i.e., residence times, types, and amount of inflows, depths, etc.) result in a disparate distribution of habitats and communities. Regional differences in the biological resources should be recognized and are summarized as follows.

Most of the North region of the bay is sea-walled and thus lacks a natural transition zone. Numerous canal discharges provide localized areas of low salinities. Oleta River State Park is located in this region. The park's Unit Management Plan (FDEP 2002) identifies several vegetative communities within the park, including maritime hammock, estuarine tidal swamp, and estuarine unconsolidated substrate (FDEP 2002). Only one listed species, golden leather fern (*Acrostichum aureum*), is an emergent wetland-related species. Just outside of the Oleta River State Park, Johnson's seagrass (*Halophila johnsonii*) is present, designated as "threatened" by the federal government. Critical habitat for Johnson's seagrass has been designated within this region.

Other seagrasses that have been noted include manatee grass (*Syringodium filiforme*) turtle grass (*Thalassia testudinum*), shoalgrass (*Halodule wrightii*), and paddle grass *(Halophila decipiens*). The salinity within this region (approaching marine), results in suitable habitat for marine macroalgae, including *Caulerpa prolifera*, *Halimeda* sp., *Udotea* sp., *Penicillus* sp. Aerial surveys and telemetry tracking have documented Florida manatees (*Trichechus manatus latirostri),* a subspecies of the West Indian manatee, have been noted in this area likely because they can forage in the seagrass beds. Turtles have also been noted within this region, including loggerhead turtles (*Caretta caretta*), green turtles (*Chelonia mydas*), and leatherback turtles (*Demochelys coriacia*). Oysters are limited in presence, but are documented to be present near the mouth of the Snake Creek Canal. A relatively diverse fish population is present, likely resulting from of the varying salinity conditions. Dominant species include the mullet (*Mugil* sp.), and blue-striped grunt (*Haemulon sciurus*). The grass beds provide habitat for a variety of fishes, including spotted seatrout (*Cynoscion nebulosus*). Also recorded within this region are Queen conch (S*trombus gigas*), long-spined sea urchins (*Diadema sp.*), nudibranchs, mollusks, and crustaceans, including spiny lobster (*Panulirus argus*) and blue crab (*Callinectes sapidus*), and various soft corals and sponges.

The Central region of the bay lies largely within Biscayne National Park and has a mangrove shoreline. Because this region experiences a wide range of salinity conditions, there is a relatively diverse assemblage of flora and fauna. Seagrasses include turtle grass (*Thalassia testudinum)*, shoal grass (*Halodule wrightii)*, paddle grass *(Halophila decipiens)*, and manatee grass (*Syringodium filiforme).* This region is also the southernmost extent of the known range of Johnson's seagrass *(Halophila johnsonii*). Attached macroalgae are abundant. The dense seagrass beds interspersed with hard bottom are habitat for a variety of crustaceans and fishes, including the commercially valuable pink shrimp (*Farfantepenaeus duorarum*).

West Indian manatees are present within the Central region. Loggerhead turtles (*Caretta caretta)*, green turtles (*Chelonia mydas)*, and leatherback turtles (*Dermochelys coriacea*) are also documented. Species such as stone crab (*Menippe mercenaria*), Spanish mackerel (*Scomberomorus maculates*), crevalle jack (*Caranx hippos*), grey snapper (*Lutjanus griseus*), blue-striped grunt (*Haemulon sciurus), barracudas* (Sphyraenidae family), and tarpon (*Megalops atlanticus*) are present. The American crocodile (*Crocodylus acutus*), spotted seatrout (*Cynoscion nebulosus*), mojarra (Gerreidae family), silver perch (*Bairdiella chrysura*), pink shrimp (*Farfantepenaeus duorarum*), and eastern oyster (*Crassostrea virginica*) have also been documented in this region.

The influence of canal inflow is small in the South region of the bay and the area is dominated by a combination of groundwater and overland flow from local runoff. The eastern shore of Barnes Sound and western shoreline of north Key Largo is contained within the Crocodile Lake National Wildlife Refuge. This entire subarea has been designated as critical habitat for the American crocodile (*Crocodylus acutus*). Hard bottom communities, dominated by corals and sponges frequently mixed with seagrasses, cover much of the submerged substrate. The middle of the Central region has extensive barren areas, but seagrasses has been steadily recolonizing the bottom. Turtle grass (*Thalassia testudimum*) is the most dominant seagrass in this region, but other species are observed, including manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii)*, widgeongrass (*Rappia maritima*), and limited *Halophila* species.

The shoreline of the South region is largely undeveloped and bordered by mangroves. Many of the same species of fish, including juvenile reef fish that use the mangrove areas in the Central region, also use the South region. A scrub mangrove and brackish marsh vegetative community is present to the west and northwest of the mangrove-lined shoreline up to the L-31E Levee and Canal. However, these areas have been disturbed and extensively invaded by exotic species, including Brazilian pepper, Australian pine, Melaleuca, Lygodium, dodder, primrose willow, and cattail. A "white zone," which is an area that shows up as a white band on black and white or color infrared satellites images of south Florida, characterizing an area of low biological productivity (Ross et al. 2002), is apparent and salinity intrusion is prominent. Inflows of fresh water have been significantly altered as a result of dredge and fill, construction of C-111 Canal, Card Sound Road and US 1, and other modifications upstream in the watershed. North Key Largo, which extends parallel to the shoreline approximately 3–5 miles to the east, separates this region of the bay from the Atlantic Ocean.

ENDANGERED AND THREATENED SPECIES

Several plant and animal species of Biscayne Bay have been designated as "endangered," "threatened," or "of special concern" under federal or state resource protection laws (**Table 10**). Such designation entitles the species to various degrees of protection, ranging from prohibitions on taking or molesting to requirements for mitigation in land development. Protection may also extend to habitat depending on the species.

The District staff's review of the life histories, habitat, and freshwater requirements of the listed species shown in **Table 10** suggest the American crocodile, the roseate spoonbill, the Florida manatee (a subspecies of the West Indian manatee), and Johnson's seagrass may be affected by a reduction in freshwater flow and/or conditions of increased salinity. Based primarily on information from the Multi-species Recovery Plan (USFWS 1999) and Barnes, Ferland and Associates, Inc. (**Appendix D**, BFA *et al.* 2004a), these species are discussed in more detail. Factors other than flow and/or salinity also impact these species survival, such as habitat loss or fragmentation, hunting, and watercraft collisions. These evaluations do not provide sufficient information to establish salinity thresholds under low flow conditions for these species.

Table 10. Endangered, threatened, or special concern species. (Source: Appendix D, BFA *et al.* 2004a)

Common Name	Scientific Name	Designation [1]		Potentially Adversely Affected by Reductions in Fresh Water?	Comments
		Florida	Federal		
Fish					
key silverside	*Menidia conchorum*	T	---	No	Year-round resident in lower Keys; euryhaline; not known to occur in Biscayne Bay
mangrove rivulus	*Rivulus marmoratus*	SSC	---	No	Year-round resident; seems to prefer salinities of 20-35 ppt; distribution largely coincident with *Cardisoma guanhumi*
key blenny	*Starksia starki*	SSC	---	No	Not known from Biscayne Bay, but present in Looe Key, Monroe County; prefers coral reef habitat and marine salinities
smalltooth sawfish	*Pristis pectinata*	---	E	No	NMFS advises species largely absent from Biscayne Bay, and that preferred patchy seagrass habitat would not be affected
Reptiles					
American alligator	*Alligator mississippiensis*	SSC	T (S/A)	No	Year-round resident, primarily in fresh water or low-salinity waters along west side of Biscayne Bay; habitat appears to somewhat overlap with *Crocodylus acutus*
Atlantic loggerhead turtle	*Caretta caretta*	T	T	No	Primarily summertime visitor, nesting on east-facing ocean beaches; prefers marine salinities
American crocodile	*Crocodylus acutus*	E	E	Yes	All sizes/ages seem to prefer intermediate (< 20 ppt) salinities; numbers are few, distributed from south boundary to Coral Gables area
Atlantic green turtle	*Chelonia mydas mydas*	E	E	No	Primarily summertime visitor, nesting on east-facing ocean beaches; prefers marine salinities
leatherback turtle	*Dermochelys coriacia*	E	E	No	Primarily pelagic, except during pring-summer nesting on east-facing beaches; prefers marine salinities
Eastern indigo snake	*Drymarchon corais couperi*	T[2]	T[2]	No	Range may include mangrove wetlands west of shoreline; year-round resident, when present
red rat snake (Lower Keys Population)	*Elaphe guttata guttata*	SSC	---	No	Not documented to occur north of the lower Keys
Atlantic hawksbill turtle	*Eretmochelys imbricata imbricata*	E	E	No	Infrequent visitor to Biscayne Bay; feeds primarily on sponges on reefs; prefers marine salinities
Florida Keys mole skink	*Eumeces egregious egregious*	SSC	---	No	Primarily inhabits sandy areas near the shoreline; northerly extent of range is Key Largo
Atlantic ridley turtle	*Lepidochelys kempi*	E	E	No	Migrant around Florida; may be an infrequent visitor to Biscayne Bay; prefers marine salinities

[1] T - threatened; E - endangered; SSC - species of special concern; T (S/A) - threatened/similarity of appearance.
[2] Updated status (FWC 2007).

Table 10. Endangered, threatened, or special concern species (Continued).

Common Name	Scientific Name	Designation [1]		Potentially Adversely Affected by Reductions in Fresh Water?	Comments
		Florida	Federal		
Birds					
roseate spoonbill	*Ajaia ajaja*	SSC ---		Yes	Uncommon year-round resident; foraging and nesting success appear to be partially dependent on estuarine salinity regimes occurring in suitable foraging habitats
piping plover	*Charadrius melodus*	T	T	No	Occasional passage migrant or winter resident; forages in intertidal zone, on sandpits, coastal inlets, and mud flats
white-crowned pigeon	*Columba leucocephala*	T ---		No	Uncommon year-round resident; primarily inhabits upland tropical hammocks, feeding on fruit-bearing species, including *Ficus* and *Metopium*
little blue eeron	*Egretta caerulea*	SSC	---	No	Fairly common year-round resident; forages in shallow waters (fresh, marine and/or estuarine); no apparent salinity preferences
reddish egret	*Egretta rufescens*	SSC ---		No	Uncommon year-round resident; spring-summer nesting in coastal mangroves; appears to prefer mesohaline to hypersaline conditions
snowy egret	*Egretta thula*	SSC	---	No	Fairly common year-round resident; forages in shallow waters (fresh, marine and/or estuarine); no apparent salinity preferences
tricolored heron	*Egretta tricolor*	SSC	---	No	Fairly common year-round resident; forages in shallow waters (fresh, marine and/or estuarine); no apparent salinity preferences
white ibis	*Eudocimus albus*	SSC	---	No	Fairly common year-round resident; forages in shallow waters (fresh, marine and/or estuarine); no apparent salinity preferences
Arctic peregrine falcon	*Falco peregrinus tundris*	E	---	No	Migrant/winter resident; opportunistic predator, primarily on other birds; no apparent salinity preferences
American oystercatcher	*Haemotopus palliatus*	SSC	---	No	Infrequent visitor, forages on benthic and benthonic organisms, relative absence may be related to lack of *Crassostrea virginica*
bald eagle	*Haliaetus leucocephalus*	T	T	No	Occasional sightings throughout the year; no documented nests within project area; primarily piscivorous; no salinity regime preference
wood stork	*Mycteria americana*	E	E	No	Uncommon winter resident, although year-round in nearby Everglades; forages primarily in shallow fresh or estuarine waters; nesting not known in project area
brown pelican	*Pelecanus occidentalis*	SSC	---	No	Abundant to common year-round resident, but no nesting colonies within project area; prefers estuarine/marine salinity regimes
black skimmer	*Rhynchops niger*	SSC	---	No	Rare to uncommon within project area; forages on small fish near surface (e.g., *Menidia, Fundulus, Anchoa,* and *Mugil);* prefers estuarine/marine salinity regimes
least tern	*Sterna antillarum*	T	---	No	Summertime breeding resident; feeds on small fish on surface; nests on barren or sparsely-vegetated beaches and rooftops near estuarine/marine salinity regimes
roseate tern	*Sterna dougallii*	T	T	No	Rare winter visitor; feeds on small fish on surface; prefers marine/estuarine salinity regimes

[1] T - threatened; E - endangered; SSC - species of special concern; T (S/A) - threatened/similarity of appearance.

Table 10. Endangered, threatened, or special concern species (Continued).

Common Name	Scientific Name	Designation [1]		Potentially Adversely Affected by Reductions in Fresh Water?	Comments
		Florida	Federal		
Mammals					
Everglades mink	*Mustela vison mink*	T	---	No	Primary habitat is the shallow freshwater marshes of the Everglades and Big Cypress Swamp; unlikely to be present in tidally affected areas of Biscayne Bay
Florida panther	*Puma concolor coryi*	E E			
Key Largo woodrat	*Neotoma floridana smalli*	E	E	No	Habitat is dry tropical forest on northern Key Largo, where it forages primarily in the forest canopy
Key Largo cotton mouse	*Peromyscus gossypinus allapaticola*	E	E	No	Habitat is primarily dry tropical forest on northern Key Largo, but it has been documented to occur in *Salicornia*-dominated coastal strand
West Indian manatee (Florida manatee)	*Trichechus manatus latirostris*	E	E	Yes	Year-round resident, but more numerous during winter; seeks canal discharges during winter for warm and/or fresh water
Corals					
pillar coral	*Dendrogyra cylindrus*	E	---	No	Present on coral reefs in eastern portions of project area; prefers marine salinity regime
Mollusks					
Florida tree snail	*Liguus fasciatus*	SSC	---	No	Inhabits upland hammocks, feeding primarily on epiphytic growths (i.e., lichens, fungi and algae on smooth-barked trees, including *Lysiloma* and *Ficus*)
Insects					
Schaus' swallowtail butterfly	*Papilio aristodemus*	E	E	No	Present in uplands (tropical hardwood hammocks and neighboring scrub area) within project area; hosts plants include Rutaceae
Miami blue butterfly	*Hemiargus thomasi bethunebakeri*	E	---	No	Present in openings and edges of tropical hardwood hammocks within project area; host plants include *Cardiospermum halicacabum,* possibly *Chiococca alba,* and various legumes
Marine Plants					
Johnson's seagrass	*Halophila johnsonii*	---	T	Yes	Prefers less than marine salinities; south end of natural range appears to be near Virginia Key

[1] T - threatened; E - endangered; SSC - species of special concern; T (S/A) - threatened/similarity of appearance.

American Crocodile: The American crocodile (*Crocodylus acutus*) is protected pursuant to the Florida Wildlife Code and the *Federal Endangered Species Act*. Its designation at both levels is "endangered" (**Table 10**). An initial recovery plan for this species was developed in 1979. The plan was updated in 1994, and recovery actions are currently being implemented in accordance with the Multi-species Recovery Plan for south Florida (USFWS 1999), which among other things, states: "The American crocodile is a valuable indicator species of the health of south Florida's estuarine environments." Critical habitat has been designated for this species, which includes most of Florida Bay, the coastal mangrove zone, the C-111 Basin, as well as areas located to the northeast of US 1 in the Biscayne Bay watershed (Turkey Point area).

Crocodiles are large, greenish-gray reptiles that reach lengths of approximately 11.4 feet (3.8 meters). Males are somewhat larger than females, both of which can be distinguished from alligators by having a longer, narrower, more tapered snout. Crocodile are found primarily in mangrove swamps and low-energy mangrove-lined bays, creeks, and inland swamps (Kushlan and Mazzotti 1989). Nest areas typically include creek banks and other locations where sandy shorelines or raised marl creek banks are adjacent to deep water, particularly at locations that are protected from wind and wave action (USFWS 1999). During the non-nesting season, crocodiles typically inhabit fresh and brackish water inland swamps, creeks, and bays (Kushlan and Mazzotti 1989). American crocodiles forage primarily from shortly before sunset to shortly after sunrise. Juveniles typically eat fish, crabs, snakes, and other small invertebrates. Adults eat fish, crabs, snakes, turtles, birds, and small mammals (Ogden 1978; 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 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. Historically, the crocodiles' range may have extended north on the east coast as far as Lake Worth Lagoon (Palm Beach County), north on the west coast to the Tampa Bay area and south to Key West.

Hunting, habitat loss, and fragmentation due to increased urbanization and agricultural land uses have contributed to the reduction of crocodiles (USFWS 1999). At varying times and locations, nest failures have also been attributed to both flooding and desiccation (Mazzotti, Kushlan, and Dunbar-Cooper 1988; Mazzotti 1989). Ogden (1978) suggests that the disappearance of crocodiles from much of Florida Bay came about, "at least in part" because of increased mortality rates among salt-stressed juveniles.

In field data collected from Florida Bay, Dunson (1982) documented that although American crocodile hatchlings are intolerant of salinities at 35 parts per thousand (ppt) water, laboratory studies indicated that most small American crocodiles maintained body mass at salinities up to 17 ppt, and some even gained mass at 26 ppt. Kushlan (1988) suggests that hatchling crocodiles possess a number of behavioral adaptations for survival in hypertonic conditions, including consuming water-laden prey items, drinking fresh water from pools and lenses riding on top of salt water, and avoidance of salt uptake.

Water salinity affects habitat use and may be locally important, especially during periods of low rainfall. Although American crocodiles have salt glands that excrete excess salt and physiological mechanisms to reduce water loss, maintenance of an osmotic balance requires access to low salinity for juveniles. However, Mazzotti and Dunson (1989) found that during the wet season, the American crocodile has the ability to grow very rapidly to a size more tolerant of higher salinities. 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 grams have sufficient mass to withstand osmoregulatory stress and are not typically believed to be affected by drought (Mazzotti and Dunson 1984).

Freshwater needs of the crocodile are usually met with frequent rainfall, which results in a "lens" of fresh water on the surface for several days after rainfall (Mazzotti and Dunson 1984). Mazzotti *et al.* (1986) observed the ecology of the juvenile American crocodile in a thermal effluent canal in Dade County and determined that hatchlings were able to tolerate and apparently thrive under temperature and salinity conditions higher than predicted by laboratory experiments with 75 hatchlings of Jamaican origin (see Dunson 1982). The study concluded that local south Florida hatchlings were likely to survive these conditions because of periodic exposure to brackish water of 4–5 practical salinity unit (psu) made available by frequent rains.

Estimates of the population of crocodiles in south Florida suggest that from historical numbers of 1,000 to 2,000, numbers dropped to all-time lows during the 1960s and 1970s during which it is thought that there were between 100 and 400 non-hatchlings (USFWS 1999), and that numbers have increased 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 as a "species of special concern" by the State of Florida (**Table 10**). Although it is protected pursuant to the *Federal Migratory Bird Treaty Act*, this species is not protected pursuant to the *Federal Endangered Species Act*. No recovery plan has been developed and there is no designated critical habitat for this species. Accounts of historical populations suggest that the spoonbill population in the United States numbered in the thousands before the 1850s, after which a rapid decline occurred. This decline was attributed to the disturbance of colonies, plume hunting, and collection of nestlings and adults for food. Between 1850 and 1920, the nationwide population was reduced to approximately 25 pairs (Allen 1942). By 1941, only one nesting colony (Bottle Key) was known to exist in Florida (Lorenz *et al.* 2002). Populations began to rebound, however, after protection mechanisms were enacted, particularly in coastal Texas and Louisiana, and estimates were that 2,200 to 2,700 nesting individuals existed in the 1970s.

Presently, although there are several widely spaced individual nesting sites in other coastal areas in the southern half of peninsular Florida, the primary nesting areas for this species are in extreme south Florida. Ninety percent of spoonbill nesting in Florida has been on mangrove islands in Florida Bay in Everglades National Park. Lorenz *et al.* (2002) reports that in recent years there have been more than 30 islands in Florida Bay that contain spoonbill nesting colonies. Cumulatively, the lack of terrestrial predators (primarily raccoons), minimal amount of human disturbance, lack of parasites and disease, and the presence and availability of prey items all likely contribute to the continued viability of individual nesting sites (Lorenz *et al*. 2002).

Spoonbills forage in shallow marine, brackish, and freshwater sites, including tidal ponds and sloughs, mud flats, mangrove-dominated pools, freshwater sloughs and marshes, and man-made impoundments (Bjork 1996). Mangrove dominated shorelines and the marine-estuarine transition zone have been documented as the primary foraging areas used by the spoonbills that nest in Florida Bay. The dwarf mangrove community that is present in areas where there is little soil accumulation overlaying a rock substrate appears to provide valuable foraging habitat for spoonbills.

Annual wet season and dry season water level fluctuations that are typically present in south Florida are critical to the nesting success of many wading birds, including spoonbills. Their annual nesting cycle is timed around the decreasing water levels that are 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. Studies by Lorenz (1999, 2000) in Florida Bay have revealed that comparatively higher, and more variable salinities in the same coastal wetlands has resulted in reduced prey biomass for foraging spoonbills. Additionally, long-term studies of spoonbill nesting territories indicate that spoonbills do respond to the destruction or degradation of their foraging grounds by relocating to other areas in closer proximity to suitable foraging spots.

Florida Manatee: The Florida manatee (*Trichechus manatus latirostris*) is a large, herbivorous, air-breathing aquatic mammal that can be found within suitable habitat throughout much of peninsular Florida. They are protected pursuant to the Florida Wildlife Code and the *Federal Endangered Species Act*, as amended. Their current designation at both levels is "endangered," although the Florida Fish and Wildlife Conservation Commission 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 areas occupied by manatees "which 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). Due to their ability to successfully 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). Although temperatures are suitable for manatees in the Florida Keys, the low number of manatees has been attributed to the lack of fresh water (Beeler and O'Shea 1988).

Water temperatures lower than approximately 20°C appear to increase the manatee's susceptibility to cold-related stress and cold-induced mortality. In north and central Florida, the manatee's wintertime distribution is primarily centered near reliable sources of warm water (e.g., power plant discharges, springs). Other manatees move south, where it is less likely that ambient water temperatures will drop below acceptable levels.

Although manatees unquestionably inhabit areas with marine salinities, and appear to survive equally well in fresh and salt waters, in areas of primarily marine salinities, 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, at least in part to reach freshwater areas.

Manatees have been identified by USFWS (1999) as an indicator species for aquatic habitats, including seagrasses and mangroves in the south Florida ecosystem. The presence of manatees has been identified as an indicator of the health and vitality of these habitats because they provide foraging, calving, resting, and mating areas for manatees. As manatees forage primarily on seagrasses, and the presence, distribution, and density of individual seagrass communities are somewhat dependant on salinity, manatees could potentially be affected by reductions in freshwater flows delivered to Biscayne Bay. Currently, however, the greatest threat to manatees within Florida is the high rate of manatee mortalities caused by watercraft collisions and other boat-related injuries or deaths. Between 1986 and 1992, watercraft collisions accounted for 37.3 percent of all manatee deaths in Florida (USFWS 1999).

Johnson's Seagrass: Johnson's seagrass (*Halophila johnsonii*) has been documented to occur only in coastal lagoons approximately 200 kilometer along the east coast of Florida and is thought to be the most spatially restricted species of seagrasses in the world (NMFS 2002). The known extent of Johnson's seagrass is from Sebastian Inlet in Brevard County to the northern reaches of Biscayne Bay, with the largest known areas within this range located in the Indian River Lagoon and Lake Worth Lagoon. Although it is observed more commonly in monotypic patches, it can be found with shoal grass and manatee grass. Based on the recovery plan, Johnson's seagrass survives in salinities from 15–43 ppt and has been observed growing perennially near the mouths of discharge canals (NMFS 2002). Tourquemada, Durako, and Lizaso (2005) found the optimal salinity to be 30 psu. Based on the information and references contained and discussed in the BFA Report (**Appendix D**, 2004a) and the Lewis Environmental Report (**Appendix E**, 2007), there is not enough information on the growth needs of this species to determine whether or not current flows in the northern portion of Biscayne Bay are optimal.

HABITAT CONNECTIVITY

The interconnection of habitats within the Biscayne Bay ecosystem is important ecologically and warrants consideration of inflow evaluation and development. The ecological connectivity between coastal and marine habitats is widely recognized (Ogden and Gladfleter 1983). Many species spend part of their lifecycles in more than one habitat, thus relying on the presence of different types of coastal habitats within an ecosystem. Habitats with structure, such as mangroves or SAV, can provide physical refuge from predation for many juvenile marine fish and are broadly acknowledged for their nursery functions. Shallow nearshore areas with reduced salinity may also provide additional protection from large predators and/or those that do not tolerate lower salinity. The use of an area as a "nursery" implies settlement of post-larvae in a nursery habitat where they grow to juveniles, followed by a directional migration to the sub-adults from a nursery habitat to an adult habitat. Thus, disturbance or environmental stress of either habitat will impact the populations that use them for this purpose.

The connection between shallow nearshore habitat (including both SAV and mangroves) and reefs may be important for numerous fish species, particularly in the Central and South regions of Biscayne Bay. Juvenile pink shrimp (*Farfantepenaeus duorarum*) immigrate to Biscayne Bay from offshore spawning grounds each year and settle in seagrass beds close to the mainland shoreline near freshwater inputs (Browder *et al.* 2005). Well-developed mangroves located near reefs may enhance both reef and estuarine fish assemblages (Day *et al.* 1989 and references therein). Several species of juvenile reef fish have been observed to use nearshore seagrass and mangrove habitats within Biscayne Bay, including the blue-striped grunt (*Haemulon sciurus)*, gray snapper (*Lutjanus griseus*), and barracuda (Sphyraenidae family) (**Appendix G**, Serafy *et al.* 2008; Faunce and Serafy 2007; Serafy, Faunce, and Lorenz 2003; Ley and McIvor 2001; Serafy *et al.* 1997).

These three species, present in Biscayne Bay, are considered estuarine transients, occupying shallow nearshore habitats as young juveniles and reef habitats as adults. Dietary changes of several reef fishes in the mangrove–seagrass–reef continuum have been studied and show that the juveniles and adults are separated ecologically and spatially for a considerable period of time (Cocheret de la Morinière *et al.* 2003). In this study, reef-inhabiting individuals of blue-striped grunt and gray snapper mainly fed on decapod crabs and prey fishes, while smaller individuals fed predominantly on tanaids, copepods, and decapods. Using stable isotopes, it was concluded that the bay inhabiting individuals of these species apparently all fed on seagrass beds and not coral reef habitats, thus confirming the spatial separation of adults from their juveniles in nursery habitats.

More examples of habitat interconnectivity are apparent, with mounting evidence that the same class of fish depend on more than one habitat in coastal areas. In a study that quantified fish assemblages in estuarine mangrove sites of northeastern Florida Bay, juvenile barracuda, grunt, and snappers were abundant in well-developed mangrove prop habitats (Ley and McIvor 2001). These species share a complex life history with major habitat shifts; as young juveniles, they occupy shallow nearshore habitats and as adults, they occupy coral reef habitats. In this same study, the density of these fish was found to be strongly correlated with mangrove prop habitats where SAV was abundant. The connectivity of the nearshore habitats provided by mangroves and SAV was reported in other nearby estuaries. In an ongoing study in the Loxahatchee Estuary, located approximately 120 miles north of Biscayne Bay, Laymen *et al.* (2008) is examining site fidelity of gray snapper (*Lutjanus griseus*) using acoustic telemetry. They report that individual fish show distinct daily movement patterns between mangrove habitat and seagrass beds, using the mangrove habitat during the day for resting periods and moving to nearby seagrass habitat during the night to feed.

An important aspect of nursery use and habitat connectivity in the nearshore coastal areas relates more specifically to fresh water. Shrimp and 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, complete life stages, consume special diet items while growing, or spawn (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 the demise of the species in that area.

EVALUATION TOOLS

Evaluation tools or models can be an important asset to ecological evaluations, often allowing synthesis of large data sets and/or simplification of complex ecological interactions. They can vary broadly in format, from complex numeric time integrated models to simple habitat suitability indexes. Empirical relationships using statistical analyses are often developed to allow synthesis of large data sets. Assuming sufficient information exists about a biological resource or community of resources, ecological modeling tools can provide a framework to compile existing information from varied sources. This allows for exploration of potential impacts of environmental variables, such as flow, where multiple factors may impact the biological interactions.

To develop such tools for coastal ecosystems, it is important to use site-specific information to the extent possible and allow calibration over a range of expected environmental conditions in locations of interest (Hunt and Doering 2005; Hunt 2008). Given the highly dynamic nature of coastal ecosystems, it may be important to consider varying growth stages and possibly re-establishment or re-population after a significant stress. Thus, an extensive and long-term effort is often required involving several years of monitoring to calibrate and validate runs for a robust model capable of producing reliable information over a broad range of conditions in the coastal environment. Models are developed with specific objectives and may not be readily used for purposes other than as designed. A few evaluation tools have been developed for the biological resources of Biscayne Bay; however, there have been limited applications. Models for seagrasses and fish are summarized as follows.

A seagrass model was developed by Fong and Hartwell (1994) to predict biomass for *Thalassia*, *Halodule, and Syringodium* genera of seagrass epiphytes and rhizophytic macroalgae in south Florida. The work was based on published information without direct experimentation as biomass was related to light, temperature, salinity and water column, and sediment phosphorus. Fong *et al.* (1997) revised the model to include the comparison of model output with values from three locations within the Central region of Biscayne Bay. The comparison of predictions and data showed the model performed reasonably well at one of the three locations, but not at the other two. Nitrogen can fuel rapid biomass increases in seagrass epiphytes and draft algae, such as *Ulva* sp., *Gracilaria* sp. and *Enteromorpha* sp., all of which have been linked to nitrogen enrichment in Biscayne Bay (Meeder and Boyer 2001). As neither model development nor validation includes the effects of nitrogen, using this tool to make predictions about water management practices in Biscayne Bay is not recommended (**Appendix D**, BFA *et al.* 2004a and **Appendix E**, Lewis Environmental 2007).

This Fong and Hartwell model was later updated and modified by Lirman and Cropper (2003) and used to describe a hypothetical restoration scenario aimed at establishing the *Halodule* genus of seagrass habitat in Biscayne Bay. Modifications were based on field surveys and salinity exposure experiments. Based on the analyses, it was suggested that salinity would need to be drastically lowered to support a mixed bed of *Thalassia* and *Halodule* genera of seagrasses in many portions of Biscayne Bay. The researchers also noted that salinity tolerance alone could not account for all the observed large-scale variability in seagrass distribution within Biscayne Bay. Other factors are suggested as important to predict the distribution dynamics of SAV within Biscayne Bay, including sediment nutrient dynamics; light availability; seagrass recruitment and rhizome expansion; competition from seagrasses, epiphytes, and drift; and rhizophytic macroalgae.

Statistical methods were used to examine patterns of fish abundance and/or diversity relative to salinity for Biscayne Bay fish (**Appendix G**, Serafy *et al.* 2008). The analysis revealed several examples of negative abundance or diversity relationships as waters became increasingly hypersaline (i.e., > 36 psu). Specific results of the analyses are discussed in **Chapter 4**. Habitat suitability curves were developed for 12 Biscayne Bay fishes and one invertebrate (pink shrimp) (*Farfantepenaeus duorarum*) and compared to those derived from throw-trap, trawl, seine, drop net, and visual census data collected from Florida Bay. An example utility of the indices developed for young of year spotted seatrout and gray snapper (*Lutjanus griseus*) is presented for a fictitious location in Biscayne Bay using a hypothetical (i.e., random number generated) salinity time series. Predicted time series of species occurrences were presented. It is noted that this type of analyses may have utility in addressing habitat suitability when other means are lacking; however, any application of this approach should only be undertaken with great caution. The authors suggest a series of field and laboratory activities be performed in conjunction with any application of indices to test the validity of the relationships presented.

RESOURCE MONITORING

Water quality and physical monitoring has been underway for more than decade in Biscayne Bay. Water quality analyses are reported in Caccia and Boyer (2005). Water quality sampling in Biscayne Bay is performed by the Miami-Dade County Department of Environmental Resource Management (Miami-Dade County DERM) and the National Oceanic and Atmospheric Administration (NOAA). Some of these data are being made available in near real-time (NOAA South Florida Ecosystem Research and Monitoring Program Web site available from: http://www.aoml.noaa.gov/sfp/data.shtml).

The Miami-Dade County DERM maintains an annual monitoring network for SAV consisting of 11 fixed sites, each with 150-foot transects. Sampled parameters include seagrass density, shoot/root/blade counts, and percent cover. Three fixed transect sites are located in the South Central region of the bay where data have been collected since 1984. In addition, a random sampling program began in 1999. This sampling program is designed to comprehensively assess cover and abundance of each seagrass type throughout the bay.

For about a decade, fish sampling has been performed by numerous parties. Much of these data have recently been compiled and synthesized (**Appendix G**, Serafy *et al.* 2008).

SENSITIVITY OF BIOLOGICAL RESOURCES TO SALINITY

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). Estuarine biota within coastal areas have adapted to a broad range of seasonally varying salinity conditions. Biota generally have a range of salinity tolerance and an even narrower range of optimal salinity ranges. Motile organisms can leave the area when salinity conditions become unfavorable, however, non-motile species must either tolerate the change or perish (Montague, Bartleson, and Ley *et al.* 1989). For a given organism, changing the salinity regime outside of its 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 organism (Livingston 1987). Thus, changes in salinity level or variability can be detrimental for some species, and favorable for others. Besides being the most important physiologically influential parameter for an estuary, salinity is the parameter most likely to change as a result of adjustments in water management. Understanding the salinity dynamics of coastal bays and lagoons and their relationship to the upstream watershed are key factors needed to establish inflow requirements.

Identifying salinity thresholds for the biological resources within the system is an important component for determining significant harm needed for establishing MFLs in south Florida. Therefore, the salinity sensitivity of estuarine resources within south Florida under low flow conditions (i.e. increased salinity) has been the focus of evaluation and review as summarized in the following section. Both the range of tolerable salinity for survival, and the duration of exposure are important factors. The interactions of the biological resources with salinity conditions can be evaluated within the transition zone or the bay. Ideally, analyses in the transition zone highlights estuarine function and focus within the estuarine low salinity areas. Estuaries contain salinity gradient or continuum, with communities or species ranging from fresh water at the head of the system to marine-dominant closer to the coast. Previously established MFLs in tidally influenced coastal systems have estuarine gradients. However, in Biscayne Bay, this gradient is limited to nearshore areas and within the mangrove fringe, which limits the resource evaluation. The wetland systems that once characterized the transition zone are highly altered – the North region being significantly urbanized; the Central region fragmented; and the South region disturbed by the presence of exotic species. Thus, the resource evaluation is limited to the following discussion, which evaluates these aspects with respect to existing information for Biscayne Bay.

Review of Salinity Tolerance Thresholds

A comprehensive review of the literature was recently completed for species in Biscayne Bay to evaluate reported species-specific salinity tolerances relevant for low flow conditions (**Appendix E**, Lewis Environmental 2007). Current literature was summarized focusing on quantitative salinity dose response relationships for the biological resources at the species, population, and community levels. The objective of this review was to survey published reports and literature to identify relationships between salinity levels and physiological and community level changes for specific species, and using this information, recommend biological resources that could be used for MFL evaluations. The list of target species included 9 groups of plants and animals, 66 taxa, and 2 (diatoms and formanifera) groups (

Table 11).

The information compiled in the Lewis Environmental Report (**Appendix E**, 2007) provides useful insights for evaluating salinity effects; however, specific relationships on which to develop a resource-based MFL were not found. Very little dosing information was found that tested responses of the biological resources to salinity in a controlled setting. A large number of publications suggested general salinity tolerances based on salinity conditions at the time of observation or collection at field sampling sites. The use of field sampling to develop tolerances is not recommended as it does not account for antecedent conditions or duration of exposure, particularly for mobile resources, such as fish. Furthermore, confounding environmental factors are common for most organisms. Estevez (2000) gives such an example using seagrasses, stating, "Many factors other than salinity affect seagrasses and the effect of some factors is profound." Some factors other than salinity known to affect seagrass distribution are light conditions, nutrients, oxygen stress, and physical conditions.

Lewis Environmental (**Appendix E**, 2007) further noted that the type of information provided by laboratory dosing experiments surveyed were not directly applicable to the range of environmental conditions that the organisms experienced and concluded a "...large effort aimed at additional species-specific salinity dosing experiments is not supported at this time." It cautioned that salinities normally inhabited by individual species tend to be much narrower in the field than in laboratory experiments. This is possibly due to the controlled conditions of laboratory work, which usually provide optimal conditions for most stressors while varying one factor; an unrealistic condition in nature. More specific recommendations are summarized in **Chapter 4**.

Additional reports and analyses specific to MFL evaluations have been compiled for stationary habitat, such as SAV in coastal south Florida (BFA 2004b). Stationary habitat has often been the focus of evaluations because salinity and inflow can be established at fixed locations. While mangroves are recognized as important habitat for fish and other organisms in south Florida, they are relatively insensitive to salinity changes over a very wide range of salinity conditions (fresh water to hypersaline) as they are facultative halophytes (**Appendix D**, BFA *et al.* 2004a and **Appendix E**, Lewis Environmental 2007).

Table 11. Species groups targeted for literature review regarding salinity dosing experiments. (Source: Lewis Environmental 2007)

KINGDOM/CLASS	TAXON	SPECIES NAME
PLANTS (Microphytes)	Bacillariophyta d	iatoms
PLANTS (Macrophytes)		
Emergent Aquatic Vegetation (EAV)		
	Avicennia germinans black	mangrove
	Cladium jamaicense sawgrass	
	Conocarpus erectus b	uttonwood
	Distichlis spicata salt	grass
	Eleocharis cellulosa gulfcoast	spikerush
	Juncus roemerianus black	needlerush
	Laguncularia racemosa white	mangrove
	Rhizophora mangle red	mangrove
	Spartina spartinae gulf	cordgrass
Submerged Aquatic Vegetation (SAV)		
	Halophila decipiens paddle	grass
	Halophila engelmanni stargrass	
	Halophila johnsonii J	ohnson's seagrass
	Halodule wrightii sho	al grass
	Ruppia maritima wigeongrass	
	Syringodium filiforme manatee	grass
	Thalassia testudinum turt	le grass
	Chara sp.	musk grass (green calcareous algae)
ANIMALS (Invertebrates)		
Foraminiferans		
	Callinectes sapidus blue	crab
	Crassostrea virginica eastern	oyster
	Farfantepenaeus duorarum	pink shrimp
	Limulus polyphemus horseshoe	crab
	Thor manningi	Manning grass shrimp
	Thor floridanus bryozoan	shrimp
	Hippolyte zostericola zostera	shrimp
	Hippolyte pleuracanthus	false zostera shrimp
	Menippe mercenaria stone	crab
Mixed species of benthic macroinvertebrates (epifauna & infauna)	Mixed	sp.

Table 11. Species groups targeted for literature review (Continued).

KINGDOM/CLASS	TAXON	SPECIES NAME
ANIMALS (Vertebrates)		
Mammals		

	Trichechus manatus West	Indian manatee
	Turciops truncatus bottlenose	dolphin
Reptiles		
	Crocodylus acutus American	crocodile
	Malaclemys terrapin tequesta	diamondback terrapin
Birds		
	Platalea ajaja roseate	spoonbill
	Egretta caerulea	little blue heron
	Egretta rufescens reddish	egret
	Egretta thula snowy	egret
	Eudocimus alba white	ibis
	Mycteria americana w	ood stork
	Pelicanus occidentalis bro	wn pelican
Fish		
	Bairdiella chrysoura silver	perch
	Centropomus undecimalis c	ommon snook
	Cynoscion nebulosus spo	tted seatrout
	Cypinodon variegatus sheepsh	ead killifish
	Eucinostomus gula silver	jenny
	Floridichthys carpio goldspotted	killifish
	Fundulus confluentus marsh	killifish
	Fundulus grandis gulf	killifish
	Haemulon sciurus bluest	riped grunt
	Haemulon plumieri white	grunt
	Haemulon parra Sailor's	choice
	Lagodon rhomboides pinfish	
	Lucania parva rainwater	killifish
	Lutjanus griseus gray	snapper
	Mycteroperca microlepis gag	grouper
	Megalops atlanticus tarp	on
	Mugil cephalus	striped mullet
	Mugil curema white	mullet
	Opsanus beta gulf	toadfish
	Sphyraena barracuda great	barracuda
	Scomberomoros maculatus	Spanish mackerel
	Caranx hippos crevalle	jack
	Sciaenops ocellatus red	drum
	Pogonias cromis black	drum
	Gerres cinereus yellowfin	mojarra
	Lutjanus apodus scho	olmaster
	Gobiosoma robustum co	de goby
	Syngnathus scovelli gulf	pipefish
	Microgobius gulosus clown	goby

Submerged aquatic vegetation has received much attention in coastal systems and a moderate amount of work exists regarding seagrass salinity tolerances and preferences, including specific dose response (**Appendix E**, Lewis Environmental 2007). The effects of exposure to high salinity on seagrasses have been a particular focus in recent field and experimental work for neighboring Florida Bay (see for example Koch and Durako 2005; Koch 2001). The SFWMD has contracted several reviews for evaluations in other coastal ecosystems in recent years, including Florida Bay and the Indian River Lagoon, which include many of the species found in Biscayne Bay (Battelle 2004; Irlandi 2006). In general, dosing experiments with seagrasses indicate that most can tolerate hypersaline conditions – as high as 65 psu for shoal grass and turtle grass. Additional stresses combined with elevated salinities, such as exposure to pulsed fresh water, nutrients, temperature, light reduction, and other factors may reduce the salinity tolerances making site-specific investigations and modeling tools important when assessing impacts of SAV on freshwater inflow.

Fish have also been the subject of consideration in numerous inflow evaluations for south Florida estuaries and recent literature review and synthesis has been conducted on fish within Florida Bay (Johnson, Browder, and Robblee 2004 and 2005) and Biscayne Bay (**Appendix G**, Serafy *et al.* 2008). A literature review and analyses were conducted relevant to freshwater flow impacts on a mix of economically and ecologically important fishes that inhabit Biscayne Bay (**Appendix G**, Serafy *et al.* 2008). Salinity affinities were assessed for 13 species of fish/invertebrates: *Cynoscion nebulous* (spotted seatrout); *Eucinostomus* sp.; *Farfantepenaeus duorarum* (pink shrimp); *Floridichthys carpio* (goldspotted killifish); *Gerres cinereus* (yellowfin mojarra); *Gobiosoma robustum* (code goby); *Haemulon parra* (blue striped grunt); *Lagodon rhomboides* (pinfish); *Lucania parva* (rainwater killifish); *Lutjanus griseus* (gray snapper); *Opsanus beta* (Gulf toadfish); *Sphyraena barracuda* (great barracuda); and *Syngnathus scovelli* (Gulf pipefish).

Community level statistical analyses of visual census fish data within Biscayne Bay, suggested a “pivot point” of 20 psu with respect to community structure (**Appendix G**, Serafy *et al.* 2008). The analyses revealed that below 20 psu, the occurrence of mojarras, snook, striped mojarra, and marsh killifish were higher, whereas occurrence of snappers, grunts, pinfish, and sergeant major were lower. The analyses also revealed several examples of negative abundance or diversity relationships as waters became increasingly hypersaline (i.e., > 36 psu). In fact, where high salinity observations were available, most statistically significant salinity trends for individual species showed abundance declines above 36 psu. Similarly, the community-level analyses showed patterns of decreased diversity and reduced assemblage when waters were greater than 36 psu. While specific salinity thresholds were not determined, the analyses establish fish patterns associated with increased salinity and reduced inflow. A key consideration is that the visual census data originate from mangrove habitats, which along the western shoreline, are primarily limited fringe areas with surface waters that are disconnected from nearby wetlands. As the estuarine area in Biscayne Bay is highly compressed, limited primarily to these nearshore areas, elevated salinity conditions in these areas could potentially have important ecological implications for estuarine function within the Biscayne Bay ecosystem, as there would be no lower salinity (upstream) transition zone refuge for estuarine species (i.e., species dominated < 20 psu).

BIOLOGICAL RESOURCES SUMMARY

The biological resources are summarized as follows:

- A conceptual model for the Biscayne Bay ecosystem, developed as part of the Everglades Restoration Program, identified four primary types of habitat: mangrove forests; herbaceous wetlands; seagrass meadows; and benthic faunal communities (soft and hard bottom). A separate model for the mangrove estuarine transition area was also developed, encompassing a brackish water ecotone of coastal bays and lakes, mangrove forests, salt marshes, tidal creeks, and upland hammocks that separate Biscayne Bay, Florida Bay, and the Gulf of Mexico from the freshwater Everglades. 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.
- In a lagoonal estuary like Biscayne Bay, herbaceous wetland, including the tidal creek ecosystem, naturally provides the hydrologic connection between the land and sea. These areas, or "transition zones," typically contain a series of ponds and wetlands, and connect to the coast via numerous tidal creeks, creating an estuarine environment by maintaining a salinity gradient from the freshwater to saltwater environment over a fairly large area. In all areas of Biscayne Bay, the connection of the bay to the freshwater wetlands has been highly altered due to urbanization, development, and the construction of canals, levees, and structures within the watershed over the past 100 years (see **Chapter 2**) resulting in lost ecological function. The North region of Biscayne Bay is highly urbanized and no longer sustains natural wetland areas. Remaining wetland communities in the South and Central Biscayne Bay regions consist primarily of two types: the saline intruded, primarily mangrove-dominated zone east of the L-31E Canal, and the exotic-dominated freshwater wetlands west of the L-31E Canal.

- Mangroves dominate the shoreline from Matheson Hammock south along the mainland and along most of the Biscayne National Park shoreline, Card Sound, and Barnes Sound. Several important functions are provided by mangrove communities, including the following: 1) protection of the shoreline from severe storm erosion; 2) dissipation of wave energy, reduction of tidal currents, and promotion of suspended sediment deposits through prop roots; 3) provision of refuge for juvenile fish and attachment surfaces for marine organisms; and 4) predation refugia, holding the highest daytime densities of juvenile and adult fish compared to other habitat types. In most areas, only a mangrove fringe area remains and represents a compressed estuarine zone that once encompassed a larger mangrove area, and included wetlands and tidal creeks.
- Seagrasses cover much of the bottom and provide the basis for substantial commercial and recreational fisheries. This community provides a food source and habitat for small fish and invertebrates.
- The mangrove and estuarine areas of Biscayne Bay support a diverse collection of littoral, mangrove, and estuarine fish. Several important game fish are strongly associated with these environments (**Table 8**) as are juvenile reef fish**.**
- The North region of the bay has different shoreline habitat than the Central and South regions. Most of the North region is sea-walled and thus lacks a natural transition zone or mangrove fringe. Although there has been extensive loss of transition zone habitat, including mangroves, the shoreline of the Central and South regions is largely bordered by mangroves. Many of the same species of fish, including juvenile reef fish that use the mangrove areas in the Central region, also use the South region.
- Review of the life histories, habitat, and freshwater requirements of species listed as endangered, threatened, or of special concern (**Table 10**) suggest the American crocodile, the roseate spoonbill, and the Florida manatee potentially could be affected by a reduction in freshwater flow and/or conditions of increased salinity. However, detailed evaluations do not provide sufficient information to establish salinity thresholds under low flow conditions. Factors other than flow and/or salinity also impact their survival, such as habitat loss or fragmentation, hunting, and watercraft collisions.

- The interconnection of habitats within the Biscayne Bay ecosystem is thought to be important ecologically. The connection between shallow nearshore habitat (including both SAV and mangroves) and reefs may be important for numerous fish species, particularly in the Central and South regions of Biscayne Bay. Juvenile pink shrimp immigrate to Biscayne Bay from offshore spawning grounds each year and settle in seagrass beds close to the mainland shoreline near freshwater inputs (Browder *et al.* 2005). Well-developed mangroves located near reefs may enhance both reef and estuarine fish assemblages (Day *et al.* 1989 and references therein).
- Several evaluation tools have been developed addressing the biological resources of Biscayne Bay, including a seagrass model, and statistically-based indices for fish.
- Water quality monitoring, fish sampling, and seagrass monitoring have been conducted within Biscayne Bay over the past 10 years.
- A review of the literature was recently completed for species present within Biscayne Bay to evaluate reported species-specific salinity tolerances (**Appendix E**, Lewis Environmental 2007). The review provides useful insights for evaluating salinity effects; however, specific relationships on which to develop resource-based MFL criteria, were not found.
- A recent community level statistical analyses of visual census fish data within Biscayne Bay, suggested a "pivot point" of 20 psu with respect to community structure (**Appendix G**, Serafy *et al.* 2008). The analyses also revealed several examples of negative abundance or diversity relationships as waters became increasingly hypersaline (i.e., > 36 psu). While specific salinity thresholds were not determined, the analyses establish fish patterns associated with increased salinity and reduced inflow. As the estuarine area in Biscayne Bay is highly compressed, limited primarily to nearshore areas, elevated salinity conditions in these areas could potentially have important ecological implications for estuarine function within the Biscayne Bay ecosystem as there would be no lower salinity (upstream) transition zone refuge for estuarine species (i.e., species dominated < 20 psu).

4

Potential Approaches for Developing Inflow Criteria

BACKGROUND

This chapter presents potential approaches for development of inflow criteria for Biscayne Bay. Minimum flows and levels have been successfully developed for several coastal systems and development of a MFL for Biscayne Bay has been considered in previous years. Thus, much of the analyses and information referenced in this chapter is in the context of MFL development (i.e., low flow conditions, establishing significant harm).

To determine a suitable approach, it is important to examine not only the relevant technical information for Biscayne Bay, but also the framework for development of coastal inflow criteria. Although inflow criteria have been established in several coastal areas of south Florida, most efforts to date have been directed toward riverine systems. The direct effect of inflow requirements in lagoonal ecosystems, such as Biscayne Bay, remains largely unstudied. As discussed in **Chapter 1**, the scope and context of protection offered by managed inflow options rests with the specific criteria of each option. For MFLs, the context is "significant harm" as defined by Rule 40E-8.021(31), F.A.C. Thus, the selection of a suitable technical approach for MFLs in south Florida systems is largely governed by the ability to establish criteria that equate to significant harm.

For water reservations, water is set aside for the protection of fish and wildlife. The fish and wildlife for which a water reservation may be set are existing native communities that use the existing habitat. The technical approach needs to establish criteria that ensure a healthy and sustainable fish and wildlife community through natural cycles of drought, flood, and population variation. Water may be reserved for whole systems or specific project areas.

It is typically desirable to use existing information and draw upon approaches that have been successful elsewhere, recognizing that the criteria can be updated when new information becomes available. However, each coastal system is unique and individual considerations must ultimately direct the evaluation. In all approaches considered, the linkage between the inflow and the resource must be established. In coastal ecosystems, salinity is typically the medial link to which both inflow and biological resources can be related. Thus, many evaluations seek to provide a technical basis to establish a salinity or range of salinity for the biological resources that meets the objectives of specific criteria. Given the number of MFLs developed in coastal south Florida, a variety of evaluations, including literature reviews and analyses, have been performed specifically in this context (i.e., establishing a link to a salinity that imparts significant harm). As many of the species found in Biscayne Bay are common to other south Florida estuaries, this information was reviewed and referenced when possible. Unfortunately, evaluations or reviews in the context of water reservations are scarce for coastal ecosystems within south Florida, and thus information specific to this context is limited.

Detailed evaluations have been performed for Biscayne Bay in recent years that are specific to MFL development. This chapter summarizes these reported evaluations and their associated recommendations, and provides additional approaches that were not previously considered by the District.

GENERAL APPROACHES IN ESTUARINE SYSTEMS

Approaches used to determine freshwater water level and inflow criteria for estuarine systems have been reviewed and categorized by Alber (2002) within the framework of the following three main effects studied:

1. Freshwater inflow
2. Estuarine-condition
3. Estuarine-resources

Each of these approaches provides a framework to establish links between the three components: inflow — condition (i.e., salinity) — resources. Freshwater inflow methods consider effects on the estuary that are related directly to quantity, quality, or timing of inflow. These methods have been used in rivers that have a relatively natural flow regime. Estuarine-condition methods relate effects on the estuary to inflow characteristics, such as salinity, sediment, or particulate material. Estuarine-resource methods examine effects on the estuary related to organism/species composition, abundance, distribution, or production in the inflow-affected area. Although these methods differ fundamentally, all must establish connections with each other. Within these three broad categories of effects, several possible approaches or methods can be considered for use in establishing water level and flow criteria. The following categories of approaches were summarized during development of the MFL criteria for the Northwest Fork of the Loxahatchee River (SFWMD 2002a).

Instream Flow: At least three general instream flow methodologies include: 1) historic-flow techniques, which rely solely on pre-existing data, 2) hydraulic techniques, which generally relate flow to the hydraulic geometry of a channel, and 3) habitat methods, which 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 approaches are considered <u>freshwater inflow-based</u>.

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 approach is considered <u>freshwater inflow-based</u>.

Habitat Overlap: As originally formulated, the habitat overlap approach has three steps: 1) identify salinities favorable for a particular species or group of species; 2) determine the location in the estuary of favorable stationary habitat, such as sediment type or submerged aquatic vegetation (SAV); and 3) identify freshwater inflows that create overlap between desired salinity and stationary habitat. To date, dynamic habitat variables other than salinity have not been considered. This approach is considered <u>estuarine condition-based</u>.

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 ecological 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. For example, the Florida Bay MFL Document (**Appendix K**, SFWMD 2006) uses an indicator species approach. This approach is considered <u>estuarine resource-based</u>.

Valued Ecosystem Component: An extension of the indicator species approach, analyses based on valued ecosystem components (VEC) account for more known or suspected intermediate variables. Valued ecosystem component analysis plays an important part in a general model for the design of eutrophication monitoring programs in south Florida estuaries as recommended by the U.S. Environmental Protection Agency (1987) for national estuary programs to characterize constraints on living resources. Valued ecological component analyses have been used by the District to establish MFLs in the Loxahatachee River (SFWMD 2002a), the Caloosahatchee River and Estuary (SFWMD 2000b), and the St. Lucie Estuary (2002b). Valued ecosystem components can be either <u>estuarine condition-based</u> or <u>estuarine resource-based.</u>

In consideration of potential approaches for development of inflow criteria for Biscayne Bay, several sources of information were reviewed:

1. Freshwater flow methods being used in riverine estuaries nationwide and elsewhere in Florida (Estevez 2000)
2. A special issue of the journal *Estuaries* dedicated to "Freshwater Inflow: Science, Policy, Management" (Estuarine Research Federation 2002)
3. Coastal/estuarine MFLs (Caloosahatchee, Loxahatchee, and St. Lucie, Florida Bay) established at the District
4. Additional efforts proposed for inflow requirement basis
5. Published literature and reports specific to Biscayne Bay

COASTAL INFLOW CRITERIA REVIEW

Inflow criteria have been developed for coastal water bodies receiving inflows within several states. Most inflow criteria have been developed for riverine systems. Application of inflow criteria has been limited in systems like Biscayne Bay, which have multiple and diffuse inflow sources.

The State of Texas has been systematically studying and instituting coastal water management policies in riverine systems for several decades and offers comprehensive models for establishing minimum inflows. Inflow diversions have created reverse estuaries and hypersaline conditions (Montagna, Kalke, and Ritter 2002). A review is provided by Estevez (2000), which describes the evolution of studies in Texas pertinent to inflow criteria in bays and estuaries and was used to provide a short synopsis here.

Texas scientists have studied species abundance and production in the estuaries and coastal waters. Abundance, although well studied, has not indicated strong relationships with inflow in Texas. No obvious relationships between inflow and phytoplankton abundance or production have been reported. Submerged aquatic vegetation and tidal plants were studied and while some tidal plants were adversely affected by salinity, estuarine or marine SAV prefer higher salinity. Meiobenthic species and abundance declines have been found, but clear patterns relating inflows to macrofaunal benthic communities have not been found. The abundances of several species of invertebrates and fishes were found to vary with respect to inflow, but the relationships are stronger for juveniles than adults.

Success in developing inflow relationships in Texas has primarily been with relating fisheries harvests or landings and other productivity indicators to inflow. After decades of applied studies and data analyses, Texas scientists have developed empirical relationships between freshwater inflows and select indicator species. Based on long-term data sets, black drum, red drum, and seatrout harvests were found to be a function of three-year average antecedent inflow. Two-year antecedent average inflows explain most of the variance in landings of oyster and blue crab, whereas antecedent yearly inflow can be used to account for variances in brown, white, and pink shrimp landings. Inflow is not the only determinant, as air temperature was found to be a second independent variable. Although these relationships are beneficial in Texas, a disadvantage of empirical relationships is that they often require developing long-term datasets and are not necessarily adaptable for widespread use. They may not be applicable in other areas or outside of assumptions used in their development.

CURRENT INFLOW CRITERIA FOR COASTAL ECOSYSTEMS IN SOUTH FLORIDA

In south Florida, minimum levels have been established for lakes, wetlands, and aquifers, while minimum flows have been set for rivers, streams, and estuaries. Minimum flows and levels criteria are adopted into the SFWMD's rules (Chapter 40E-8, F.A.C.) and are implemented through the District's Consumptive Use Permitting and Water Supply Planning programs. To date, the District has established inflow criteria for 16 water bodies. Four of these water bodies, the St. Lucie River and Estuary, the Caloosahatchee River and Estuary, Florida Bay, and the Northwest Fork of the Loxahatchee River are influenced by daily ocean tides and cover a sizable portion of the coastal environment. Minimum flows and levels for these water bodies are typically expressed in terms of: a minimum mean monthly flow; a mean monthly salinity concentration that should not be exceeded; a duration (number of days) criteria that should not be exceeded; and an acceptable return frequency (number of years) in which these low flow, high salinity events should occur under natural conditions. **Table 12** provides a summary of MFL criteria established by the District for the four water bodies influenced by daily ocean tides.

In an addition to the MFLs established for these four south Florida estuaries, the District has also established MFLs for the coastal Biscayne aquifer. The Biscayne aquifer underlies eastern Palm Beach, Broward, and Miami-Dade counties – representing one of most highly permeable aquifers in the world. The Biscayne aquifer serves as a major source of drinking water for south Florida's Lower East Coast urban areas; provides water for local wells, canals, lakes, wetlands, and agriculture; and provides an important source of groundwater flow to estuaries, such as Biscayne Bay and Florida Bay. The criteria were developed to prevent saltwater intrusion.

More information about established minimum flows and levels, including the technical support documents produced for each water body is available from the SFWMD's MFL Web page available from: http://www.sfwmd.gov/watersupply.

Chapter 40E-8, F.A.C. containing Governing Board adopted MFL criteria are available from: https://www.flrules.org/.

All current south Florida coastal MFLs use a specific freshwater VEC or indicator species with a defined salinity threshold (**Table 12**). Beyond the threshold, the resource experiences significant harm and takes more than two years to recover. The established salinity thresholds are all below marine conditions and are based on flows that prevent saltwater intrusion at specific locations within the upper estuarine environment or freshwater interface (**Table 12**). Most of south Florida coastal MFLs are for riverine systems with a salinity sensitive oligohaline reach or freshwater floodplain VEC, where the salinity sensitive species or community is established. Florida Bay is the exception, because like Biscayne Bay, it is not riverine-based, but a lagoonal system that receives diffusely distributed wetland/tidal creek inflows.

Table 12. Summary of coastal MFLs in south Florida. Note: All coastal MFLs specify a freshwater VEC or indicator in the upstream reaches of the estuary. The established salinity measures are lower than marine. (Further information is available from: http://www.sfwmd.gov/watersupply - Click on *Minimum Flows and Levels* from the left menu.)

System	Type of Inflow	Approach	Resource	Measures	Rule Date
Caloosahatchee River	ine	VEC in upstream reach	Freshwater SAV; *Vallisneria americana*	> 10 ppt (30-day prior); > 20 ppt (daily avg.)	2000
St. Lucie - North Fork	Riverine VEC	in upstream reach	Oligohaline Zone	maintain 0.5 ppt	2002
Loxahatchee Riverine		VEC in freshwater floodplain	Freshwater floodplain vegetation community (6 selected species)	> 2 ppt (20-day avg.)	2003
Florida Bay - Northeastern	Wetland/ Tidal Creek	Indicator Sp. in Transition Zone	Freshwater SAV Community; *Ruppia maritima*	> 30 ppt (30-day avg.)	2006

In Florida Bay, a resource-based approach using the SAV indicator species *Ruppia maritima* (widgeongrass) located in ponds within the Everglades/Florida Bay transition zone was used to establish the MFL (SFWMD 2006). The Everglades/Florida Bay transition zone is contained within Everglades National Park and is thus a natural undeveloped area. Impacts to this resource are defined in terms of a freshwater inflow regime and corresponding salinity levels required for survival of this freshwater SAV habitat. During periods that characterize impacts to *R. maritima*, the SAV with the highest salinity tolerance 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 on the downstream Florida Bay ecosystem. The Biscayne Bay ecosystem differs significantly from Florida Bay because the Biscayne Bay transition zone has been highly altered. The Biscayne Bay ecosystem includes: the City of Miami and surrounding urban areas; agricultural areas; mining; a nuclear power facility with a large cooling water operation; and other modified land uses previously described. In contrast, the Everglades/Florida Bay transition zone is a federally protected natural area contained within Everglades National Park. The overland flow component from natural wetlands that once connected the natural tidal creeks to regional freshwater sources no longer exists for Biscayne Bay due to development in the watershed. Flood protection is provided by water management of the regional system of canals that drain the low-lying areas and generally prevent inundation. Thus, it is not likely that a similar approach could be used in Biscayne Bay.

Additional MFLs within the State of Florida have been established that include consideration of estuarine freshwater needs (Montagna, Alber, and Doering eds. 2002). Similar to south Florida, these MFLs are established for riverine systems. In contrast to the resource approaches described, the Southwest Florida Water Management District uses an inflow-based approach, which links water withdrawal to daily flow, thereby preserving natural stream flow variation (Flannery, Pebbles, and Montgomery 2002). Mattson (2002) also describes an inflow approach for the Suwannee River and Estuary in northern Florida, which assumes that the altered regime (i.e., the minimum inflow criteria) "is still near natural in terms of magnitude, frequency duration, and timing of freshwater flows... ." The emphasis is on maintaining the natural inflow regime needed to sustain a salinity condition that will support complex estuarine biological communities. This is in contrast to the resource-based approach that starts with the biological resource to be protected and establishes a relationship to salinity condition, and then quantifies the flow needed to maintain that salinity. The primary limitation of this method, as described in Alber (2002), is that it relies on the natural flow variation under existing conditions and thus may not be applicable for hydrologically altered systems, such as Biscayne Bay.

OTHER CRITERIA

Restoration targets have been proposed for Biscayne Bay (**Appendix B**, USDOI 2008; USACE and SFWMD 2007), which have different objectives than minimum inflow needs. Although the targets may provide a link between inflow and salinity, two key differences make application of restoration targets difficult in the context of minimum inflow criteria. First, restoration targets are based on future conditions rather than existing conditions. Second, restoration targets are intended to represent long-term optimal salinity conditions for maintenance and enhancement of biological resources. Two major restoration projects are in the planning stages within the Biscayne Bay watershed – the Biscayne Bay Coastal Wetlands Project and the C-111 Spreader Canal Project. More information is available from the Everglades Plan Web site about the Biscayne Bay Coastal Wetlands project: http://www.evergladesplan.org/pm/projects/proj_28_biscayne_bay.cfm and the C-111 Spreader Canal Project: http://www.evergladesplan.org/pm/projects/proj_29_c111.aspx. Additional restoration targets for Biscayne Bay have been proposed by Biscayne National Park (**Appendix B**, USDOI 2008).

Restoration targets associated with the projects can be viewed as estuarine condition-based approaches that are intended to meet salinity based goals for optimal estuarine function within Biscayne Bay. These targets are not tied to any specific species or resource; rather they account for a broad range or suite of species and resources that favor estuarine conditions. Because restoration is the objective, most of the targets specify a range of optimal salinity conditions for sustaining a suite species, rather than defining the point of significant harm, as in the case of the MFL determination. The exception is the hypersalinity target proposed by Biscayne National Park, which is not intended as a restoration target, but meant to represent a "lower bound on the amount of fresh water to maintain living natural resources characteristic of any current areas of the bay" (**Appendix B**, USDOI 2008). This type of target is more in line with objectives of minimum flow evaluations.

SUMMARY OF PREVIOUS BISCAYNE BAY EVALUATIONS

Two relatively recent evaluations were contracted by the SFWMD to describe the biological resources, establish ecological relationships with inflow, and provide recommended approaches that could be used to develop inflow criteria for Biscayne Bay.

- Freshwater Flow and Ecological Relationships in Biscayne Bay (**Appendix D**, BFA et al. 2004a).
- Literature Review of the Effects of Salinity Levels and Variations on Biscayne Bay Biological Resources (**Appendix E**, Lewis Environmental 2007).

The documents primarily explored potential links between resources and salinity. Inflow relationships were not established in either report. Both reviews were performed in the context of MFL evaluations and sought to identify salinity criteria and/or conditions that equate to significant harm. Salinity links or relationships pertaining to other types of regulatory tools, such as water reservations, were not part of the purpose or scope of the evaluations, and thus, were not considered. The recommended approaches summarized by both Lewis Environmental (**Appendix E**, 2007) and BFA *et al.* (**Appendix D**, 2004a) are primarily based on the protection of an existing resource within specified subareas of Biscayne Bay. Both reports recognize that a significant amount of supplemental information would be required before MFL criteria could be established using resource-based options. However, the type of analysis or information that would be needed is not included in the reports. In the absence of a recommended approach, maintaining existing inflows was suggested as a default option. Some recommendations (i.e., the salinity/habitat gradient plan) were primarily restoration alternatives that do not establish a link between an inflow quantity to a biological resource. *None of the recommendations identified a salinity threshold or length of exposure to a specific salinity that would be needed to develop inflow criteria.*

Barnes, Ferland and Associates Report

Barnes, Ferland and Associates, Inc. (BFA) (**Appendix D**, 2004a,) was contracted by the SFWMD to summarize the ecosystem components and recommend potential approaches for MFL development in Biscayne Bay. The report divides the bay into six subregions (**Figure 18**) and a rating system was used to develop a short list of potential approaches, including separate recommendations for each of subregions. Nine different approaches were considered for each region: VEC; indicator species; presence/absence/vitality of preferred habitat; ecological preservation; pre-development scenario; requirement for preferred fish communities; community index; food web support; and soil characteristics. The rating was based on a qualitative index of 1 through 5; 5 being the strongest approach candidate. In five of the six subregions, a rating of 2 was indicated for the strongest candidate. *In all areas, it was noted that the technical information on which to base a MFL presented substantial data limitations and thus, overall it was recommended that a contingency plan be established.* The contingency plan recommended by BFA *et al.* (2004a) states that all existing flows from wetlands into the bay should be maintained until further scientific information is available on the status and inflow requirements of the species present or other species are documented. No specific justification or technical basis is described for this recommendation.

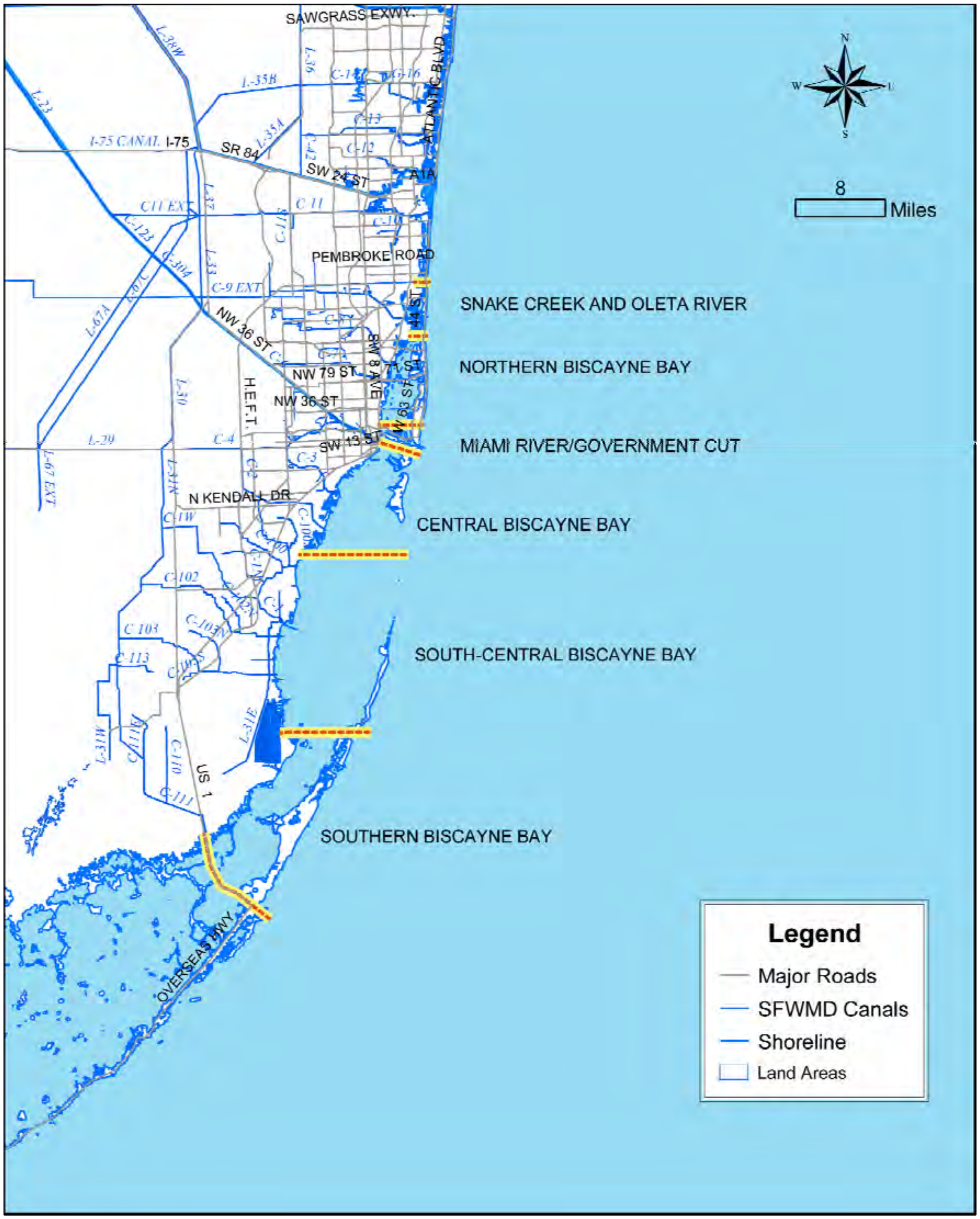


Figure 18. Subregions used for resource-based approaches. (Source: Appendix D, BFA *et al.* 2004a)

Snake Creek/Oleta River: A resource-based approach using indicator species Johnson's seagrass, West Indian manatee, or American oyster rated highest overall with 2 out of a possible 5. Although these species are present in this area, appropriate oyster mapping has not been done and the health or condition of existing populations is not known. Further, it is not known whether existing flows are optimal or suboptimal for either the Johnson's seagrass or West Indian manatee species. Given the amount of unknown information, the contingency plan (i.e., maintain existing inflows) was ultimately recommended.

Northern Biscayne Bay: A resource-based approach using either manatee seagrass, or spotted seatrout as the indicator species rated highest, at 2 out of 5. Data linking freshwater flows and salinities that are protective of these species are lacking and the previously described contingency plan was recommended.

Miami River/Government Cut: A resource-based approach using a community index with fish and/or invertebrates as a biotic indicator was recommended. This approach involves the development of a mathematical formula to describe the ecological health of a system. This option was rated 2 out of 5. This approach links salinity with the biotic indicator; however, it is not clear how this approach could be linked to a freshwater inflow. In addition, the high data uncertainties and polluted bottom sediments in this area make this a weak option and the contingency plan was again recommended.

Central Biscayne Bay: A resource-based approach using the indicator species shoal grass, and pink shrimp received the highest rating with 2 out of 5. Linkages between salinity, submerged habitat, and specific species use (i.e., shrimp) have not been adequately developed to define significant harm. Again, the contingency plan was recommended for this area of Biscayne Bay.

South Central Biscayne Bay: A resource-based approach using a sustainable pink shrimp harvest as the VEC was rated 2 out of 5. In this case, the VEC is the productivity of the pink shrimp. Given similar uncertainties found in central Biscayne Bay, the contingency plan was again recommended.

Southern Biscayne Bay: A resource-based approach using food web support (i.e., linking a food source to an indicator or VEC) and then linking the VEC to a salinity and inflow rated 4 out of 5. A forage food base was intended as the target reference point for the roseate spoonbill (and other birds) and the American crocodile. This approach is based on restoring wetlands in this area as a result of C-111 modifications to provide habitat use of the marsh wetlands adjacent to the bay. Until the potential salinity impacts are better quantified and a significant harm-based salinity link is established, the contingency plan was recommended.

Lewis Environmental Report

The evaluations provided by Lewis Environmental (**Appendix E**, 2007) expanded on the previous effort (**Appendix D**, BFA *et al.* 2004a), but focused on salinity thresholds obtained from an extensive literature survey of dosing information, which could be linked with biota and used to establish significant harm consistent with developing MFL criteria. This additional review and information did not provide further options for VECs or strengthen existing links as indicated by previous work (BFA *et al.* 2004a). Lewis Environmental (**Appendix E**, 2007) introduced an additional option for some areas termed the "salinity/habitat gradient plan." The basic concept of this plan is to create a gradient of topography, vegetation, and salinity at the edge of western side of the bay, such that an optimum habitat and salinity along the gradient for an estuarine community of organisms could be established (i.e., VECs and indicator species). This plan as described, does not link an inflow with specific salinity conditions as would be needed to develop inflow criteria. This type of restoration involves construction of an area that contains or mimics a more natural flow regime (wetland/tidal creek) and habitat (vegetated marsh, mangrove) for the bay than the existing canal flow. The recommendations contained in Lewis Environmental (**Appendix E**, 2007) are summarized as follows.

Snake Creek/Oleta River: The information about salinity dosing did not suggest any change from the recommendation of BFA *et al.* (**Appendix D**, 2004a), as previously described.

Northern Biscayne Bay: The information about salinity dosing did not suggest any change from the recommendation of BFA *et al.* (**Appendix D**, 2004a), and supports the concept that manatee grass has a physiological optimum lower than that of turtle grass and shoal grass.

Miami River/Government Cut: The information about salinity dosing did not suggest any change or clarification from the recommendation of BFA *et al.* (**Appendix D**, 2004a).

Central Biscayne Bay: The information presented (**Appendix E**, Lewis Environmental 2007) and contained in BFA *et al.* (**Appendix D**, 2004a) indicated that nutrients associated with freshwater inputs might not be conducive to maintaining or restoring habitat for shoal grass. The restoration habitat/salinity gradient plan, as previously described, was recommended for this area.

South Central Biscayne Bay: The restoration habitat/salinity gradient plan entering the bay was recommended for this area. Given the possibility of nutrient impacts to macroalgae and seagrasses, a constructed wetland to remove nutrients prior to discharge to the bay was recommended as part of this plan.

Southern Biscayne Bay: It was recommended that the potential impacts of increased salinities on the juvenile American crocodile need to be better quantified. In the interim, the contingency alternative of maintaining the existing freshwater inflow was recommended and the implementation of the salinity/habitat gradient restoration plan considered in this subarea.

ADDITIONAL INFLOW CONSIDERATIONS

Determining links between freshwater inflow, condition, and biological resources is a critical element in establishing technically-based inflow criteria. The approaches considered are a key aspect of inflow evaluations – determining how those links may be established. Equally important, the information and analyses used to establish the links require a context and can be very different for each regulatory option(s) being considered. For example, it is likely the information or evaluations that would be used to establish a link between salinity and significant harm of a resource (i.e., MFL) would not also be used to establish a link between salinity and protection of existing fish and wildlife (i.e., water reservation). Despite the different information and evaluations needed to provide the technical basis for each criterion, some generalizations may be applicable across the separate regulatory options.

Estuarine function, discussed as follows, is apparent in Biscayne Bay by the multitude and diversity of such resources found in nearshore areas that receive inflow and have a variable salinity range as presented in **Chapter 3**. Estuarine function is also an important feature in Biscayne Bay because the landward transition zone that historically provided this function no longer exists and is currently confined to nearshore areas receiving inflow. A condition-based approach that establishes a salinity condition related to estuarine function may be preferred in Biscayne Bay.

The Importance of Estuarine Function

The ecological characteristics of estuaries are strongly related to the influx of fresh water and associated materials from their watersheds (Day *et al.* 1989). However, there is no known standard for defining "estuarine function" in terms of a specific salinity or range of salinity. Foremost among the influences 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). Changing freshwater flow can also affect estuarine habitat quality and availability and estuarine productivity by changing the supply of nutrients to the estuary. As the hydrology of the Biscayne Bay watershed has been extensively modified over the past century, it would follow that some changes in estuarine function have also occurred during this time. Given the extensive nature of the changes, it would not be realistic to expect inflow criteria to fully restore lost function.

Evidence exists for the presence of estuarine organisms and function within the nearshore areas of Biscayne Bay, as presented in **Chapter 3**. Maintaining such function as it relates to inflow may be an important consideration for Biscayne Bay. The protection of estuarine function within nearshore Biscayne Bay would be justifiable given the highly modified transition zone located landward of the shoreline mangroves, which currently exists and no longer supports a salinity gradient. The gradient is present in nearshore mangroves and SAV habitat receiving groundwater and overland flow, which supports juvenile fish and other estuarine biota. The gradient is also found in many areas receiving canal inflow. The current areas receiving inflow serve as the existing transition zone. The level of protection and frequency, timing, and specifics of the link to salinity required to support estuarine function would need to be evaluated in the context of the specific inflow criteria considered.

In general, organisms living in estuaries have characteristic salinity tolerances and salinity optima. Thus, the bay's salinity regime will determine how well these organisms can function, whether motile organisms will move out of the estuary to seek habitat with more suitable conditions, or whether they 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 example, a decline in the abundance or quality of habitat will have a detrimental impact on fauna that use this habitat. A decline in populations of small forage fish or invertebrates will have an adverse affect on publicly recognizable sport fish populations.

All estuarine organisms are physiologically affected to some degree by the salinity level and 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 or gradual changes may not be immediately lethal, but may 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 example, 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). As discussed in the Habitat Connectivity section of **Chapter 3**, shrimp, 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, complete life stages, consume special diet items while growing, or spawn (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 the demise of the species in that area.

The spatial expanse of estuarine conditions is also important for inflow needs. The estuarine zone is a region of intermediate salinity created by mixing of fresh and salt water. The estuary would eventually revert to a marine system becoming hypersaline in shallow areas when evaporation rates are in excess of rainfall if freshwater input was absent. As the amount of freshwater input declines, the region that is characterized by estuarine salinities diminishes, 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 (e.g., 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 (e.g., corridors) are required for some processes to occur (Micheli and Peterson 1999). Examples of spatial requirements include range and area for mobile organisms; minimum predator-prey encounter areas; minimum sustainable seagrass patch size; and minimum refugia for protective habitat. 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 direct salinity effects on biological organisms, changes in freshwater flow result in both system-wide changes in the physical size of the entire estuarine ecosystem, and in local changes in spatial dimensions required for many ecological processes.

The spatial expanse of the existing estuarine area is particularly relevant given its current limited area in Biscayne Bay, which is restricted to nearshore mangrove fringe or canal inflow points. If inflow is not high enough to support a nearshore area that has estuarine salinity conditions in Biscayne Bay, then organisms that seek lower salinity have very limited options – some will likely become stressed or even perish. Furthermore, competition for space or food can reduce not only the estuarine resource, but also diminish its function.

The function of the estuarine environment has much broader implications. Although the specific attributes of estuaries are difficult to define, the widespread use by larvae and juveniles of many species has led to the concept of "estuarine dependence," implying that the estuary is required for some part of the life cycle of certain organisms. Within estuaries, there are three primary nursery areas: wetlands (including salt marshes and mangroves and the shallow marsh fringe areas and mudflats), the low salinity area at the head of the estuary, and grass beds (Day *et al.* 1989). An important feature of low salinity habitats is maintaining ecosystem species diversity by providing a diversity of habitats.

The fish community in Biscayne Bay has been studied and characterized over the past decade and these results may be used to support the importance of estuarine function. Several evaluations establish a link between salinity and the fish community. Although it would be difficult to establish a link related to significant harm, as would be needed for a MFL, links may be possible using other inflow options, such as water reservations. The ecological categories of littoral, mangrove, and estuarine fish communities overlap considerably in Biscayne Bay as described in **Chapter 3**. Estuarine species thrive under reduced salinity, and therefore, benefit from freshwater inflows. The low and fluctuating salinities in these habitats exclude most marine fish, which leaves hardy estuarine species with less competition for the abundant food supplies. The connection of adjacent habitats (i.e., mangrove-seagrass) for juvenile species is also an important consideration as discussed in **Chapter 3**. Several important game and food fish are strongly associated with these environments in Biscayne Bay (**Table 8**), emphasizing the importance of maintaining estuarine habitat in the bay.

Field data support differences in fish assemblages in a reduced salinity environment in Biscayne Bay and provide a link between salinity conditions and the fish community. A recent multivariate analysis using Biscayne Bay visual census data suggested a salinity pivot point of 20‰ with respect to community composition and structure (**Appendix G**, Serafy *et al.* 2008). This salinity can be thought of as the breakpoint between a community of fish dominated by estuarine – dependent species (< 20‰) vs. a community dominated by marine species (> 20‰). The occurrence of snapper (Lutjanidae family) and grunt (Haemulidae family) species, pinfish (*Lagodon rhomboides*), and sergeant major (*Abudfduf saxatilis*) diminished at salinities below 20‰ and those of snook, (*Centropomus* sp.), small mojarra (*Eucinostomus* sp.), striped mojarra (*Diapterus plumieri*), and marsh killifish (*Fundulus confluentus*) increased (**Appendix G**, Serafy *et al.* 2008).

The analysis presented in Serafy *et al.* (**Appendix G**, 2008) also shows several examples of negative abundance or diversity relationships as waters become increasingly saline (i.e., > 36 psu), indicating another link to salinity conditions. Where high salinity observations were available, most of the statistically significant salinity trends for individual taxa showed abundance declines beyond 36 psu. Similarly, the community level analyses showed patterns of decreased diversity and reduced assemblage structure when salinity was greater than 36 psu. Examples include species such as grunt, pinfish, and snapper, classified in the marine-dominant communities. Thus, species of the marine-dominant and estuarine-dominant community, show negative abundance or diversity at higher salinity conditions. Although considered reef fish as adults, the grunt and snapper exhibit ontogenic life cycles and use the nearshore mangrove and seagrass habitats as juveniles.

Other studies in southern Biscayne Bay and adjacent areas corroborate expected differences in the fish community among regions with different salinity characteristics, further establishing the link between salinity conditions and fish community. Fish community structure was examined in response to salinity differences between sites located in southern Biscayne Bay, C-111, and Taylor Slough watersheds (Lorenz *et al.* 2000). The analyses showed that each watershed had a distinct fish community characterized by different species. Southern Biscayne Bay was characterized by meso- and polyhaline species, whereas Taylor Slough contained freshwater species. The C-111 Basin was predominately composed of oligohaline species. Non-metric Multidimensional Scaling ordination plots were used to demonstrate that the species composition was significantly different for each of the four categories (i.e., fresh water, oligohaline, mesohaline, polyhaline) and that there were significant differences in these categories within each watershed.

Relating the Occurrence of Hypersalinity to Estuarine Function

There is no doubt that estuarine function depends on freshwater inflow, which when mixed with seawater, creates areas of reduced salinities. Thus, salinity is linked to estuarine function as marine or above condition would not be considered "estuarine." The salinity of the oceans is generally between 33‰ and 37‰, with 35‰ often used as the open ocean average (Sverdrup, Johnson, and Fleming 1942). Salinities above 37‰ are often referred to as "hypersaline" and can occur in shallow marine areas when evaporation is high (i.e., the summer months) and exceeds net inflow, including rainfall and freshwater sources. Many marine organisms are surprisingly tolerant of such conditions and can survive periodic exposure. In some central basins in nearby Florida Bay that are not influenced by freshwater inflow, salinities can reach greater than 50‰ (Lee *et al.* 2006).

Salinity observations from ongoing monitoring indicate that several areas within all regions of Biscayne Bay can become hypersaline (i.e., > 37‰), particularly during the dry season and in the early wet season (**Appendix C:** Salinity Observations). Similarly, recent mass balance analyses indicate that the average monthly salinities in the South and Central (Inshore) regions are hypersaline, particularly during dry years (**Figure 10**). Although many organisms within the bay ecosystem can tolerate periodic exposure to hypersaline conditions, estuarine function in the same area would not be sustained. The estuarine area of Biscayne Bay is limited to the nearshore and mangrove fringe under current conditions and does not include a natural salinity transition zone, such as Florida Bay (SFWMD 2006). The resource-based criteria developed for the Florida Bay MFL established a salt tolerant freshwater species (*R. maritima*) as an indicator of the freshwater SAV community in the transition zone. Supporting information confirmed that the downstream coastal embayments would be hypersaline (defined in this case as > 40‰) when the upstream MFL criteria are exceeded. This was illustrated along a habitat gradient, which included three habitats: a mangrove-dominated transition zone containing ponds connected by tidal creeks, a coastal embayment on the northern boundary, and a northeastern open water area (SFWMD 2006). A key finding of the field and modeling analyses showed that hypersalinity in the coastal embayments of Florida Bay translated to decreases in SAV diversity and fauna, thereby impacting the Florida Bay ecosystem.

In the case of Biscayne Bay, developing a similar salinity transition zone gradient would not be possible because of the degree of modification in the area landward of the nearshore mangrove fringe. However, it may be possible to develop inflow criteria using a condition-based approach in Biscayne Bay based on preserving estuarine function by establishing criteria related to hypersalinity. In Biscayne Bay, hypersalinity would pose even more of a concern due to the limited available estuarine area relative to Florida Bay. Given the lack of a landward transition zone (i.e., the salinity gradient is within the bay), even mobile species cannot move "upstream" into less saline waters if salinity conditions become undesirable in the coastal areas. Thus, the estuarine function would be temporarily lost in the Biscayne Bay ecosystem when these areas become hypersaline.

To develop inflow criteria based on a condition-based approach using an estuarine-function/hypersalinity metric for Biscayne Bay, three key actions are necessary and would require further consideration and evaluation:

- Define hypersalinity or the "salinity condition."
- Establish the timing, frequency, and duration of the condition.
- Establish the location and distribution of both salinity and inflow measurements.

The first consideration is defining "hypersaline conditions" or "hypersalinity" as related to estuarine function. Although it can be considered 37‰, the Florida Bay MFL referenced hypersaline conditions as >40‰, showing that at salinities >40‰, the composition of SAV and fish composition changed in the coastal embayments. In contrast, a recently compiled analysis of flow targets for Biscayne National Park defines nearshore hypersalinity in the Biscayne National Park as 30‰ due to the estuarine character of the area (**Appendix B**, USDOI 2008). The specific salinity used would have to be related to some biological resource or ecosystem component that meets the definition of the inflow option being considered. For example, in the case of a MFL, "significant harm" would need to be linked to the salinity specified (i.e., loss of estuarine function that takes two years to recover). Establishing the salinity link for a water reservation would need to relate to protection of fish and wildlife.

The second consideration is establishing the timing, frequency, and duration that the defined condition (i.e., "hypersalinity") could occur. In terms of timing, the season and hydrologic conditions would need to be considered. Establishing criteria under low flow conditions in the dry season would be the most obvious start. Alternately, criteria could be established in both the wet and dry seasons if specific reasons (i.e., related to ecological function) could be justified. The frequency and duration of the salinity condition are also key considerations that need technical justification. Existing monitoring capability could be a limiting factor. Currently, monthly grab samples are the most widespread type of existing salinity sampling used throughout the bay and may be more difficult to monitor or fund than a continuous monitoring site that is linked to maintaining estuarine function.

The third consideration is establishing the location(s) for both salinity and inflow measurements. Evaluations to establish specific connections with canal flows or stages, groundwater levels within the watershed, and salinity conditions at locations throughout the bay need to be conducted. Given the differences in the type and quantity of flows within the different regions of Biscayne Bay (**Figure 9**), it is likely that several locations would be needed and different inflows (i.e., groundwater or canal flow) may need to be targeted in the different regions or subareas of the bay. The distribution would need to be considered and again may be limited by existing monitoring or funding. It is anticipated that regression analyses or other statistical evaluations could be used with existing monitoring locations to determine a relationship between water levels or canal stage or flow within the watershed and salinity under low flow conditions within Biscayne Bay. Preliminary analyses in the Central region of Biscayne Bay indicate that relationships are possible using either groundwater stage or canal flow (**Appendix H:** Example Analyses to Link Salinity with Inflow and/or Water Level). Data are currently being compiled to conduct further evaluations, which will target salinity stations at additional nearshore areas where data and observations exist.

SUMMARY OF POTENTIAL APPROACHES FOR DEVELOPING INFLOW CRITERIA

Potential approaches are summarized as follows:

- Three primary methods are used to determine freshwater inflow criteria for estuarine systems: freshwater inflow-based, estuarine condition-based, and estuarine resource-based. Within the three primary methods, numerous approaches can be taken.
- All established south Florida coastal inflow criteria specify a freshwater VEC or indicator species with a defined salinity threshold. Beyond the threshold, the resource experiences significant harm and takes more than two years to recover. The established salinity thresholds are all below marine conditions and are based on flows that limit saltwater intrusion at specific locations within the upper estuarine (non-marine) environment (**Table 11**).

- Most inflow criteria for south Florida estuaries are MFLs that have been established in riverine systems containing a salinity sensitive oligohaline reach or freshwater floodplain where the salinity sensitive species or community exists.
- The lack of a landward estuarine gradient in Biscayne Bay, a wetland lagoonal system with numerous inflow sources, makes development of inflow criteria challenging. All of the SFWMD coastal ecosystem inflow criteria rely on the existence of an upstream area where specific increased salinity impacts (i.e., resulting from low flow) to a freshwater or non-marine biological resource can be demonstrated. The nearshore salinity gradient that currently exists within Biscayne Bay does not support the type of condition or organisms previously used. Most resources within the bay ecosystem can tolerate marine conditions.
- Restoration targets have been proposed for Biscayne Bay, which are based on future conditions rather than existing conditions. Such targets have different objectives than minimum inflow needs. They are intended to represent long-term optimal salinity conditions for maintenance and enhancement of biological resources. The underlying basis used in target development would not meet the definitions required to develop minimum inflow criteria. The exception is the hypersalinity target proposed by Biscayne National Park, which is not intended as a restoration target, but meant to represent a "lower bound on the amount of fresh water needed to maintain living natural resources characteristic of any current areas of the bay" (**Appendix B**, USDOI 2008).
- The recommended approaches summarized by both Lewis Environmental (**Appendix E**, 2007) and BFA *et al.* (**Appendix D**, 2004a) are primarily based on protection of existing biota within specified subareas as defined in a MFL context. Both reports conclude that a significant amount of supplemental information would be required before inflow criteria could be established using these options. The suggested default option was to maintain the existing inflow. Some recommendations (i.e., the salinity/habitat gradient plan) were primarily restoration alternatives that do not establish a minimum inflow link with salinity or resources. None of the recommendations identifies a salinity threshold or length of exposure to a salinity value that would be needed to develop resource-based inflow criteria consistent with MFLs, but potentially could be applied to other regulator tools.
- The protection of estuarine function within nearshore Biscayne Bay would be justifiable given the existing highly modified transition zone located landward of the shoreline mangroves, which no longer supports a salinity gradient. The salinity gradient currently exists within the bay in nearshore mangrove and SAV habitat that receives

groundwater, canal, and overland flow, which supports juvenile fish and other estuarine biota. These areas serve as the existing transition zone. The levels of protection and frequency, timing, and specifics of the link to salinity required to support estuarine function would need to be evaluated in the context of the specific inflow criteria being considered.

- The fish community in Biscayne Bay has been studied and characterized over the past decade and these results could be used to support the importance of estuarine function. Several evaluations establish a link between salinity and the fish community. Although it would be difficult to establish a link related to significant harm, as would be needed for a MFL, links may be possible using other regulatory tools.
- A condition-based approach that establishes a salinity condition related to estuarine function may be a preferred in Biscayne Bay. It may be possible to establish a salinity-fish community link based on preserving estuarine function by establishing criteria related to hypersalinity. Given the lack of a landward transition zone (i.e., the salinity gradient is within the bay), even mobile species cannot move "upstream" into less saline waters if salinity conditions become undesirable in the coastal areas. Thus, the estuarine function would be temporarily lost in the Biscayne Bay ecosystem when these areas become hypersaline.
- Salinity observations from ongoing monitoring indicate that several areas within all regions of Biscayne Bay can become hypersaline (i.e., > 37‰) particularly during the dry season and in the early wet season. Similarly, recent mass balance analyses indicate that the average monthly salinities in the South and Central (Inshore) regions are hypersaline, particularly during dry years. Although many organisms within the bay ecosystem can tolerate periodic exposure to hypersaline conditions, estuarine function in these areas would be temporarily lost.
- To develop inflow criteria based on a condition-based approach using an estuarine-function/hypersalinity metric for Biscayne Bay, three key actions are necessary and would require further consideration and evaluation:
    1. Define hypersalinity or the "salinity condition."
    2. Establish the timing, frequency, and duration of the condition.
    3. Establish the location and distribution of both salinity and inflow measurements.

Glossary

Accretion The gradual accumulation of new material on top of older sediments or soils.

Acre-foot The volume of water that covers 1 acre to a depth of 1 foot; 43,560 cubic feet; 1,233.5 cubic meters; 325,872 gallons.

Aquifer A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.

Basis of Review (BOR) From the District's publication, *Basis of Review for Water Use Permit Applications within the South Florida Water Management District*. Read in conjunction with Chapters 40E-2 and 40E-20, Florida Administrative Code (F.A.C.), the Basis of Review further specifies the general procedures and information used by District staff for review of water use permit applications with the primary goal of meeting District water resource objectives.

Benthic Pertaining to the bottom or sediment habitats of a body of water.

Biscayne aquifer A portion of the surficial aquifer system, which provides most of the fresh water for public water supply and agriculture within Miami-Dade, Broward, and southeastern Palm Beach County. It is highly susceptible to contamination due to its high permeability and proximity to land surface in many locations.

Central and Southern Florida Flood Control Project (C&SF Project) A complete system of canals, storage areas, and water control structures spanning the area from Lake Okeechobee to both the east and west coasts and from Orlando south to the Everglades. It was designed and constructed during the 1950s by the U.S. Army Corps of Engineers (USACE) to provide flood control and improve navigation and recreation.

Confining unit A body of significantly less permeable material than the aquifer, or aquifers, that it stratigraphically separates. The hydraulic conductivity may range from nearly zero to some value significantly lower than that of the adjoining aquifers.

Consumptive Use Permitting (CUP) The issuance of permits by the SFWMD, under the authority of Chapter 40E-2, F.A.C., allowing withdrawal of water for consumptive use.

Control structure A man-made structure designed to regulate the level/flow of water in a canal or water body (e.g., weirs, dams).

Diatom Any of a class (Bacillariophyceae) of minute planktonic unicellular or colonial algae with silicified skeletons.

Dinoflagellates An order of flagellate protozoans in the class of Phytamastigophorea; most members have fixed shapes determined by thick covering plates.

Drawdown The vertical distance between the static water level and the surface of the cone of depression.

Elevation The height in feet above mean sea level according to North American Vertical Datum (NAVD) of 1988 or the National Geodetic Vertical Datum (NGVD) 1929. May also be expressed in feet above mean sea level (MSL) as reference datum.

Endangered species As designated by the Commission, a species, subspecies, or isolated population of a species or subspecies which is so few or depleted in number or so restricted in range or habitat due to any man-made or natural factors that it is in imminent danger of extinction, or extirpation from Florida, as determined by paragraph (a), (b), (c), (d), or (e) in accordance with Rule 68A-27.0012, F.A.C.

Epiphytes Plants that derive their moisture and nutrients from the air and rain, usually growing on other plants.

Existing Legal Use of Water A water use authorized under a District water use permit or is existing and exempt from permit requirements.

Fauna All animal life associated with a given habitat.

Flora All plant life associated with a given habitat.

Florida Administrative Code (F.A.C.) The Florida Administrative Code is the official compilation of the administrative rules and regulations of state agencies.

Florida Department of Environmental Protection (FDEP) The SFWMD operates under the general supervisory authority of the FDEP, which includes budgetary oversight.

Florida Statutes (F.S.) The Florida Statutes are a permanent collection of state laws organized by subject area into a code made up of titles, chapters, parts, and sections. The Florida Statutes are updated annually by laws that create, amend, or repeal statutory material.

Food web The totality of interacting food chains in an ecological community.

Fresh water Water with less than 1,000 mg/L of TDS, but drinking water, by U.S. Environmental Protection Agency (USEPA) standards, must have less than 500 mg/L of TDS. (~1 mg/L TDS = 0.5 mg/L of Chlorides.)

Governing Board Governing Board of the South Florida Water Management District.

Harm As defined in Chapter 40E-8, F.A.C., the temporary loss of water resource functions that results from a change in surface or groundwater hydrology and takes a period of one to two years of average rainfall conditions to recover.

Hectare A unit of measure in the metric system equal to 2.47 acres (10,000 square meters).

Hydraulic conductivity A coefficient of proportionality describing the rate at which water can move through an aquifer or other permeable medium.

Hypersaline Salinity conditions that are above what is typical of open marine conditons. Salinity conditions in excess of typical marine conditions.

Invasive species Species of plants or animals that are not naturally found in a region (nonindigenous). They can sometimes aggressively invade habitats and cause multiple ecological changes, including the displacement of native species.

Isotope One of two or more atoms with the same atomic number, but with different numbers of neutrons.

Lagoon A body of water separated from the ocean by barrier islands, with limited exchange with the ocean through inlets, and having no connections to a major river or estuary.

Levee An embankment to prevent flooding or a continuous dike or ridge for confining the irrigation areas of land to be flooded.

Littoral Of, relating to, situated, or growing on or near a shore.

Macroalgae Large-celled, photosynthetic algae that act as a natural water filter by reducing the available levels of phosphate and nitrogenous waste.

Macroinvertebrate Aquatic invertebrates, including insects, crustaceans, mollusks, and worms, which inhabit a river channel, pond, lake, wetland, or ocean.

Marl A mixture of clays, carbonates of calcium and magnesium, and remnants of shells, forming a loam that is useful as a fertilizer.

Macrophytes Visible (non-microscopic) plants found in aquatic environments. Examples in south Florida wetlands include sawgrass, cattail, sedges, and lilies.

Mesohaline Term to characterize waters with salinity of 5 to 18 parts per thousand (ppt), due to ocean-derived salts.

Model A computer model is a representation of a system and its operations, and provides a cost-effective way to evaluate future system changes, summarize data, and help understand interactions in complex systems. Hydrologic models are used for evaluating, planning and simulating the implementation of operations within the SFWMD's water management system under different climatic and hydrologic conditions. Water quality and ecological models are also used to evaluate other processes vital to the health of ecosystems.

National Geodetic Vertical Datum (NGVD) 1929 A geodetic datum derived from a network of information collected in the United States and Canada. It was formerly called the "Sea Level Datum of 1929" or "mean sea level (msl)." Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific coasts, it does not necessarily represent local mean sea level at any particular place.

Nekton Macroscopic organisms swimming actively in water, such as fish (contrast to plankton).

Oligohaline Term to characterize water with salinity of 0.5 to 5.0 parts per thousand (ppt), due to ocean-derived salts.

Peat Any mass of semi-carbonized vegetable tissue formed by partial decomposition in water of various plants, especially mosses of the genus *Sphagnum*. Peat varies in consistency from turf to slime. As it decomposes its color deepens, old peat being dark brown or black, and keeping little of the plant texture. According to its formation, it is known as Bog Peat (mosses), Heath Peat, or Meadow Peat (grasses and sedges), Forest Peat, or Wood Peat (trees), and Sea Peat (seaweeds).

Pelagic Pertaining to region of a lake at depths 33–66 feet or more, characterized by deposits of mud or ooze by the absence of vegetation.

Permeability The capacity of a porous rock, sediment, or soil for transmitting a fluid.

Phytoplankton The floating, usually minute, plant life of a body of water.

Recharge (Hydrologic) The downward movement of water through soil to groundwater; the process by which water is added to the zone of saturation; or the introduction of surface water or groundwater to groundwater storage, such as an aquifer.

Salinity Of or relating to chemical salts, usually measured in parts per million (ppm) or milligrams per liter (mg/L) or practical salinity units (psu).

SEAWAT A program developed to simulate three-dimensional, variable-density, transient groundwater flow in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations.

Serious Harm As defined in Chapter 40E-8, F.A.C., the long-term loss of water resource functions resulting from a change in surface water or groundwater hydrology.

Significant Harm As defined in Chapter 40E-8, F.A.C., the temporary loss of water resource functions, which result from a change in surface water or groundwater 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.

Slough A channel in which water moves sluggishly, or a place of deep muck, mud, or mire. Sloughs are wetland habitats that serve as channels for water draining off surrounding uplands and/or wetlands.

South Florida Water Management Model (SFWMM) An integrated surface water-groundwater model that simulates the hydrology and associated water management schemes in most of south Florida using climatic data from January 1, 1965, through December 31, 1995. The model simulates the major components of the hydrologic cycle and the current and numerous proposed water management control structures and associated operating rules. It also simulates current and proposed water shortage policies for the different subregions in the system.

Stage The height of a water surface above an established reference point (datum or elevation).

Stressor Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).

Submerged Aquatic Vegetation (SAV) Wetland plants that exist completely below the water surface.

Surface Water Improvement and Management (SWIM) Plan A comprehensive statewide program for restoring and protecting priority surface waters of state or regional significance, established in 1987 by Sections 373.451–373.4595, Florida Statutes.

Species of special concern As designated by the Commission, a species, subspecies, or isolated population of a species or subspecies which is facing a moderate risk of extinction, or extirpation from Florida, in the future, as determined by paragraph (a), (b), (c), (d), or (e) in accordance with Rule 68A-27.0012, F.A.C.

TABS-MDS U.S. Army Corps of Engineers' multidimensional hydrodynamic model.

Threatened species As designated by the Commission, a species, subspecies, or isolated population of a species or subspecies which is facing a very high risk of extinction, or extirpation from Florida, in the future, as determined by paragraph (a), (b), (c), (d), or (e) in accordance with Rule 68A-27.0012, F.A.C.

Transmissivity A term used to indicate the rate at which water can be transmitted through a unit width of aquifer under a unit hydraulic gradient. It is a function of the permeability and thickness of the aquifer, and is used to judge its production potential.

Trophic level One of the hierarchical strata of a food web characterized by organisms which are the same number of steps removed from the primary producers.

Valued ecosystem component (VEC) Any part of the environment that is considered important by the proponent, public, scientists or government involved in the assessment process. For SFWMD studies, the VEC approach is based on the concept that management goals for the natural system can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit the natural system.

Water quality The physical, chemical, and biological condition of water as applied to a specific use. Federal and state guidelines set water quality standards based on the water's intended use, that is, whether it is for recreation, fishing, drinking, navigation, shellfish harvesting, or agriculture.

Water Reservations State law on water reservations, in Section 373.223(4), F.S., defines water reservations as follows: "The governing board or the department, by regulation, may reserve from use by permit applicants, water in such locations and quantities, and for such seasons of the year, as in its judgment may be required for the protection of fish and wildlife, or the public health and safety. Such reservations shall be subject to periodic review and revision in the light of changed conditions. However, all presently existing legal uses of water shall be protected so long as such use is not contrary to the public interest."

Water Supply Plan Detailed water supply plan developed by the District under Section 373.0361, F.S., providing an evaluation of available water supply and projected demands, at the regional scale. The planning process projects future demand for 20 years and recommends projects to meet identified needs.

Water table The surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere; defined by the level where water within an unconfined aquifer stands in a well.

Wellfield One or more wells producing water from a subsurface source. A tract of land that contains a number of wells for supplying a large municipality or irrigation district.

Zooplankton The passively floating or weakly swimming, usually minute, animal life of a body of water.

References

Alber, M. 2002. A Conceptual Model of Estuarine Inflow Management. *Estuaries*, 25(6B):1246–1261.

Allen, R.P. 1942. *The Roseate Spoonbill: Research Report 2*. National Audubon Society, New York, NY, 142.

Ault, J.S. el al. 2001. *Site Characterization for Biscayne National Park: Assessment of Fisheries Resources and Habitats*. NOAA Technical Memorandum NMFS-SEFSE-468, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Miami, FL.

BFA et al. 2004a. *Freshwater Flow and Ecological Relationships in Biscayne Bay*. Prepared by Barnes, Ferland and Associates, Inc. in association with Lewis Environmental Services, Inc.

BFA et al. 2004b. *Seagrasses, Associated Fauna and Faunal Habitat Requirements Documentation and Analysis*. Contract No. C-15967. Prepared by Barnes, Ferland and Associates, Inc. in association with Lewis Environmental Services, Inc.

Battelle. 2004. *Literature Review of Salinity Effects on Seagrasses in Florida Bay*. Prepared for the South Florida Water Management District, West Palm Beach, FL, 30.

Beeler, I.E. and T.J. O'Shea. 1988. *Distribution and Mortality of the West Indian Manatee (Trichechus manatus) in the Southeastern United States: A Compilation and Review of Recent Information*. NTIS #PB88-207980/AS, National Technical Information Service, Springfield, VA, 613.

Berkeley, S.A. 1984. *Fisheries Assessment*. Department of Environmental Resource Management, Miami-Dade County, Miami, FL.

Bjork, R. 1996. "Roseate Spoonbill." In Rare and Endangered Biota of Florida, Volume 5: Birds. University Press of Florida, Gainesville, FL.

Brand, L.E. 1988. *Assessment of Plankton Resources and their Environmental Interactions in Biscayne Bay, Florida*. Miami-Dade County Department of Environmental Resource Management, Miami, FL.

Broward County Department of Environmental Protection. 1994. *Delineation of Saltwater Intrusion*. Broward County, Environmental Protection, Geographical Information Systems, Fort Lauderdale, FL, 1 sheet.

Browder, J.A. et al. 2005. Biscayne Bay Conceptual Ecological Model. *Wetlands*, 25(4):854-869.

Browder, J.A. and D. Moore. 1981. "A New Approach to Determining the Quantitative Relationship between Fishery Production and the Flow of Fresh Water to Estuaries." In Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Volume 1, eds. R.D. Cross and D.L. Williams. FWS/OBS-81/04:403–430. U.S. Fish and Wildlife Service, U.S. Department of Interior.

Buchanan, T.J. and H. Klein. 1976. "Effects of Water Management of Freshwater Discharges to Biscayne Bay." In Biscayne Bay: Past/Present/Future, eds. A. Thorhaug and A. Volker. Sea Grant Special Publication No.5, University of Miami, Coral Gables, FL, 113–132 .

Caccia, V.G. and J. N. Boyer. 2005. Spatial Patterning of Water Quality in Biscayne Bay, Florida as a Function of Land Use and Water Management. *Marine Pollution Bulletin,* 50:1416–1429.

Cocheret de la Morinière, E. et al. 2003. Onotogentic Dietary Changes of Coral Reef Fishes in the Mangrove-seagrass-reef Continuum: Stable Isotopes and Gut Content Analyses. *Marine Ecology Press Series*, Volume 246:279-289.

Cooper, R.M. and J. Lane. 1987. *An Atlas of Eastern Dade County Surface Water Management Basins*. Technical Memorandum. Resource Planning Department, South Florida Water Management District, West Palm Beach, FL, 97.

Davis, J.H., Jr. 1943. The Natural Features of Southern Florida, Especially the Vegetation of the Everglades. *Florida Geological Survey*, Bulletin 25:311.

Davis, S. 2004. "Everglades Mangrove Estuaries Conceptual Model, Appendix A-3." In Comprehensive Everglades Restoration Plan, Part 1: Monitoring and Supporting Research. U.S. Army Corps of Engineers, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL, A53–78.

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

Day, J.W. et al. 1989. Estuarine Ecology. Wiley and Sons, Inc. New York, NY.

deSylva, D.P. 1976. "Fishes of Biscayne Bay, Florida." In: Biscayne Bay: Past/Present/Future, eds. A. Thorhaug and A. Volker, Sea Grant Special Publication No. 5, University of Miami, Miami, FL. 181–202.

Duever, M.J. et al. 1994. "The Climate of South Florida and Its Role in Shaping the Everglades Ecosystem." In Everglades: The Ecosystem and Its Restoration, eds. S.M. Davis and J.C. Ogden. St. Lucie Press, Delray Beach, FL, 225–248.

Dunson, W.A. 1982. Salinity Relations of Crocodiles in Florida Bay, USA. *Copeia*, 1982(2):374–385.

ECT. 2005. *FATHOM Enhancements and Implementation to Support Development of MFL for Florida Bay (Final)*. No. C-15975-WO05-05. Prepared for the South Florida Water Management District by Environmental Consulting and Technology, Inc., New Smyrna Beach, FL, 80.

ECT. 2008. *Final Report: Biscayne Bay Freshwater Budget and the Relationship of Inflow to Salinity*. Contract STO60588-WO06. Prepared by Environmental Consulting and Technology, Inc. for South Florida Water Management District, West Palm Beach, FL.

Enfield, D.B., A.M. Mestas-Núñez, and P. Trimble. 2001. The Atlantic Mutlidecadal Oscillation and its Relation to Rainfall and River Flows in the Continental United States. *Geophysical Research Letters,* 28(10):2077–80.

Estévez, E.D. 2000. *A Review and Application of Literature Concerning Freshwater Flow Management in Riverine Estuaries*. Technical Report Number 680. Prepared for the South Florida Water Management District by the Center for Coastal & Tropical Ecology, Mote Marine Laboratory, Sarasota, FL.

Estuarine Research Federation. 2002. Freshwater Inflow: Science, Policy, and Management. Organized by Montagna, P.A., M. Alber, and P.H. Doering, *Dedicated Issue of Estuaries:* Issue 25(6B).

Faunce C.G. and J. E. Serafy. 2007. Nearshore Habitat Use by Gray Snapper (*Lutjanus griseus*) and Bluestriped Grunt (*Haemulon sciurus*): Environmental Gradients and Ontogenetic Shifts. *Bulletin of Marine Science*, 80(3):473-495.

FDEP. 2002. *Oleta River State Park Unit Management Plan*. Florida Department of Environmental Protection, Tallahassee, FL.

Fish, J.E. and M. Stewart. 1991. *Hydrogeology of the Surficial Aquifer System of Dade County, Florida*. USGS Water Resources Investigation Report 90(4108):50. U.S. Geological Survey, Tallahassee, FL.

Fitterman, D.V. and M. Deszcz-Pan. 1999. "Geophysical Mapping of Saltwater Intrusion in Everglades National Park." In Proceedings, Third International Symposium on Ecohydraulics, July 1999, Salt Lake City, UT.

Flannery, M.S., E.B. Peebles, and R.T. Montgomery. 2002. A Percentage-of-Streamflow Approach for Managing Reductions of Freshwater Inflows from Unimpounded Rivers to Southwest Florida Estuaries. *Estuaries*, 25(6B):1318–1332.

Fong, P. et al. 1997. Investigating the Management Potential of a Seagrass Model through Sensitivity Analysis and Experiments. *Ecological Applications*, 7(1):300–315.

Fong, P. and M.A. Hartwell. 1994. Modeling Seagrass Communities in Tropical and Subtropical Bays and Estuaries: A Mathematical Model Synthesis of Current Hypotheses. *Bulletin of Marine Science*, 54:757–781.

Fonseca, M.S. and J.S. Fisher 1986. A Comparison of Canopy Friction and Sediment Movement between Four Species of Seagrass and with Reference to their Ecology and Restoration. *Marine Ecology Progress Series,* 29:15–22.

FWC. 2007. *Florida's Endangered Species, Threatened Species, and Species of Special Concern.* Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. http://myfwc.com/imperiledspecies/pdf/Threatened-and-Endangered-Species-2007.pdf.

Gilmore, R.G. 1987. "Fish, Macrocrustacean, and Avian Population Dynamics and Cohabitation in Tidally Influenced Impounded Subtropical Wetlands." In Proceedings of a Symposium in Waterfowl and Wetland Management in the Coastal Zone of the Atlantic Flyway, eds. W.R. Whitman and W.H. Meredith. Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Hartman, D.S. 1974. *Distribution, Status, and Conservation of the Manatee in the United States.* Technical Report NTIS PB81-140725. Prepared for the National Fish and Wildlife Lab, U.S. Fish and Wildlife Service, 247.

Hazen and Sawyer, P.C. 2005. *Biscayne Bay Economic Study: C-15869 Task 3 Economic Baseline and Trend Report.* Draft Report Submitted to the South Florida Water Management District, West Palm Beach, FL.

Houde, E.D. and J.A. Lovdal. 1985. Patterns of Variability in Ichthyoplankton Occurrence and Abundance in Biscayne Bay, Florida. *Estuarine, Coastal and Shelf Science*, 18:403-419.

Hunt, M.J. 2008. "Essential Considerations for Development of Ecological Modeling Tools." In Conference Proceedings of the 10th International Conference on Estuarine and Coastal Modeling. American Society of Civil Engineering Press, Reston, VA.

Hunt, M.J. and P.H. Doering. 2005. "Significance of Considering Multiple Environmental Variables When Using Habitat as an Indicator of Estuarine Condition." In ed. S.A. Bortone, Estuarine Indicators, CRC Press, Boca Raton, FL, 221–227.

Irlandi, E. 2006. *Literature Review of Salinity Effects on Submerged Aquatic Vegetation (SAV) Found in the Southern Indian River Lagoon and Adjacent Estuaries.* Final Report Submitted to the South Florida Water Management District, West Palm Beach, FL, 35.

Ishman, S.E. et al. 1998. A Record of Ecosystem Change: Manatee Bay, Barnes Sound, Florida. *Journal of Coastal Research*, 26:125-138.

Jaap, W.C. 1984. *The Ecology of South Florida Coral Reefs: A Community Profile.* FWS/OBS 82/08. U.S. Field and Wildlife Service, Washington, D.C., 138.

Johnson, D.R., J.A. Browder, and M.B. Robblee. 2004. *Literature Review of Selected Organisms and Salinity-related Responses from Florida Bay and Surrounding Areas.* Final Report. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Johnson, D.R., J.A. Browder, and M.B. Robblee. 2005. *Statistical Models of Florida Bay Fishes and Crustaceans to Evaluate Minimum Flow Levels in Florida Bay*. Contribution No. PRD 04/05–06. Protected Resources and Biodiversity Division of the Southeast Fisheries Science Center, Miami, FL, 474.

Koch, M.S. 2001. *Assessment of Impacts of Hypersalinity on the Seagrass Thalassia testudinum in Florida Bay during a Persistent Drought in South Florida*. Contract 9696-0736. Final Report Submitted to South Florida Water Management District, West Palm Beach, FL, 23.

Koch, M.S. and M.J. Durako. 2005. *High Salinity and Multiple Stressor Effects on Seagrass Communities of Northeast Florida Bay (Final)*. Contract No. C-12430. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Kohout, F.A. 1960. Cyclic Flow of Salt Water in the Biscayne Aquifer of Southeastern Florida. *Journal of Geophysical Research*, 65(7P):2133–2141.

Kohout, F.A. 1964. *The Flow of Fresh Water and Salt Water in the Biscayne Aquifer of the Miami Area in Sea Water in Coastal Aquifers*: U.S. Geological Survey, Water-Resources Investigations Report 93-4164, 1 sheet.

Kohout, F.A. and M.C. Kolipinski. 1967. "Biological Zonation Related to Ground-Water Discharge along the Shore of Biscayne Bay, Miami, Florida." In Estuaries: American Association for the Advancement of Science, Publication No. 83:488–499.

Kushan, J.A. 1988. Profiles: Conservation and Management of the American Crocodile. *Environmental Management*, 12(6):777–90.

Kushlan, J.A. and F.J. Mazzotti. 1989. Historic and Present Distribution of the American Crocodile in Florida. *Journal of Herpetology,* 23:1–7.

Langevin, C.D. 2001. Simulation of Ground-Water Discharge to Biscayne Bay, Southeastern Florida. USGS Water Resources Investigation Report 00-4251. U.S. Geological Survey, Tallahassee, FL. http://water.usgs.gov/ogw/seawat/langevin.gw200341.pdf.

Layman, C. et al. 2008. "Daily Movement Patterns of Fishes Related to Local Habitat Characteristics." In Proceedings, Fourth Loxahatchee River Watershed Science Symposium. April/May 2008, Jupiter, FL.

Lee, T.N. et al. 2002. "Transport Processes Linking South Florida Coastal Ecosystems." In The Everglades, Florida Bay, and Coral Reefs of the Florida Keys, eds. J.W. Porter and K.G. Porter. CRC Press, Boca Raton, FL, 309–342.

Lee, T.N. et al. 2006. On Florida Bay Hypersalinity and Water Exchange. *Bulletin of Marine Science*, 79(2):301-327.

Lewis Environmental. 2007. *Literature Review of the Effects of Salinity Levels and Variations on Biscayne Bay Biological Resources*. Final Report. Prepared for the South Florida Water Management District by Lewis Environmental Services, Inc., Valrico, FL.

Ley, J.A. and C.C. McIvor. 2001. "Linkages Between Estuarine and Reef Fish Assemblages: Enhancement by the Presence of Well Developed Mangrove Shorelines." In The Everglades, Florida Bay, and the Coral Reefs of the Florida Keys: an Ecosystem Sourcebook, eds. J. W. Porter. CRC Press, Boca Raton, FL, 539–562.

Lietz, A.C. 2000. *Analysis of Water Quality Trends at Two Discharge Stations – One within Big Cypress National Preserve and One near Biscayne Bay – Southern Florida, 1966-1994*. Water Resources Investigations Report 00-4099, U.S. Geological Survey, Tallahassee, FL.

Lirman, D. and W. Cropper, Jr. 2003. The Influence of Salinity on Seagrass Growth, Survivorship and Distribution within Biscayne Bay, Florida: Field, Experimental, and Modeling Studies. *Estuaries*, 26(1):131–141.

Livingston, R.J. 1987. "Historic Trends of Human Impacts on Seagrass Meadows of Florida." In *Florida Marine Research*. Publication 92. Proceedings of the Symposium on Subtropical-tropical Seagrasses of the Southeastern United States, eds. M.J. Durako, R.C. Phillips, and R.R. Lewis. Florida Department of Natural Resources, Tallahassee, FL, 139–56.

Lorenz, J.J. 1999. The Response of Fishes to Physicochemical Changes in the Mangroves of Northeast Florida Bay. *Estuaries,* 22:500–17.

Lorenz, J.J. et al. 2000. Analyses of Hydrographic Parameters and the Demersal Fish Community of the Coastal Wetlands of Southern Biscayne Bay with Comparisons to Watersheds in Florida Bay. 2000-2006 Final Report to the National Marine Fisheries Service.

Lorenz, J.J. et al. 2002. "Nesting Patterns of Roseate Spoonbills in Florida Bay 1935–1999: Implications of Landscape-scale Anthropogenic Impacts." In The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook, eds. J.W. Porter and K.W. Porter. CRC Press, Boca Raton, FL, 563–606.

Mattson, R.A. 2002. A Resource-based Framework for Establishing Freshwater Inflow Requirements for the Suwannee River Estuary. *Estuaries*, 25(6B):1333–1342.

Mazzotti, F.J. 1989. Factors Affecting the Nesting Success of the American Crocodile, *Crocodylus acutus*, in Florida Bay. *Bulletin of Marine Science,* 44:220–28.

Mazzotti, F.J. et al. 1986. Field and Laboratory Observations on the Effects of High Temperature and Salinity on Hatchling *Crocodylus acutus*. *Herpetologica,* 42(2):191–96.

Mazzotti, F.J. and W.A. Dunson. 1984. Adaptations of *Crocodylus acutus* and Alligator for Life in Saline Water. *Comparative. Biochemistry. Physiology*, 79A(4):641–46.

Mazzotti, F.J. and W.A. Dunson. 1989. Osmoregulation in Crocodilians. *American Zoologist*, 29(3):903–920.

Mazzotti, F.J., J.A. Kushlan, and A. Dunbar-Cooper. 1988. Desiccation and Cryptic Nest Flooding as Probable Causes of Egg Mortality in the American Crocodile, *Crocodylus acutus,* in Everglades National Park, Florida. *Florida Scientist*, 51(2):65–72.

McIvor, C.C., J.A. Ley, and R.D. Bjork. 1994. "Changes in Freshwater Inflow from the Everglades to Florida Bay, Including Effects on Biota and Biotic Processes: A Review." In Everglades: The Ecosystem and Its Restoration, eds. S.M. Davis and J.C. Ogden. St. Lucie Press, Delray Beach, FL, 117–46.

Meeder, J. and J.N. Boyer. 2001. *Total Ammonia Concentrations in Soil, Sediments, Surface Water, and Groundwater along the Western Shoreline of Biscayne Bay with the Focus on Black Point and a Reference Mangrove Site*. Final Report to the National Park Service, Biscayne National Park, Homestead, FL.

Meyer, F.W. 1989. *Hydrogeology, Groundwater Movement, and Subsurface Storage in the Floridan Aquifer System in Southern Florida*. USGS Professional Paper 1403-G. U.S. Geological Survey, 59.

Miami-Dade County DERM. 1992. *Manatee Protection Plan*. Department of Environmental Resource Management, Miami-Dade County, Miami, FL, 74.

Micheli, F. and C.H. Peterson. 1999. Estuarine Vegetated Habitats as Corridors for Predator Movements. *Conservation Biology,* 13:869–81.

Montagna, P.A. et al. 2008. *Peer Review: Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay*. Texas A&M University, Corpus Christi, TX.

Montagna, P.A., M. Alber, and P.H. Doering, eds. 2002. Dedicated Issue of Estuaries Freshwater Inflow: Science, Policy, Management Issue. *Estuarine Research Federation*, Volume 25 (6B).

Montagna, P.A., R.A. Kalke, and C. Ritter. 2002. Effect of Restored Freshwater Inflow on Macrofauna and Meiofauna in Upper Rincon Bayou, Texas, USA. *Estuaries*, 25(6B):1436–1447.

Montague, C.L., R.D. Bartleson, and J.A. Ley. 1989. *Assessment of Benthic Communities along Salinity Gradients in Northeastern Florida Bay*. Final Report to the South Florida Research Center, Everglades National Park, Homestead, FL.

Myers, R.L. 1986. Florida's Freezes: An Analog of Short-duration Nuclear Winter Events in the Tropics. *Florida Scientist,* 49:104–15.

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

NMFS. 2002. *Recovery Plan For Johnson's Seagrass (Halophila johnsonii)*. Prepared by the Johnson's Seagrass Recovery Team for the National Marine Fisheries Service, Silver Springs, MD.

NOAA. 2000. *Biscayne Bay: Environmental History and Annotated Bibliography*. National Status and Trends Program for Marine Environmental Quality, Technical Memorandum NOS NCCOS CCMA 145, National Oceanic and Atmospheric Administration, Silver Springs, MD.

Ogden, J.C. 1978. "American Crocodile." In Amphibians and Reptiles (Volume 3 of Rare and Endangered Biota of Florida), ed. R.W. McDiarmid. University Presses of Florida, Gainesville, FL, 21–22.

Ogden, J.C. et al. 2005. The Use of Conceptual Ecological Models to Guide Ecosystem Restoration in South Florida. *Wetlands*, Vol. 25(4):795–809.

Ogden, J.C. and E.H. Gladfelter. 1983. *Interactions between Mangrove, Seagrass Beds, and Coral Reefs in the Coastal Zones of the Caribbean*. UNESCO Reports in Marine Science Volume 23.

Parker, G., G.E. Ferguson, and S.K. Love. 1955. *Water Resources of Southeastern Florida, with Special Reference to the Geology and Groundwater of the Miami Area*. USGS Paper No. 1255. U.S. Geological Survey, Washington, D.C., 965.

Powell, J.A. and G.B. Rathbun. 1984. Distribution and Abundance of Manatees along the Northern Coast of the Gulf of Mexico. *Northeast Gulf Science*, 7(1):1–28.

Renken, R.A. et al. 2005. *Impact of Anthropogenic Development on Coastal Ground-Water Hydrology in Southeastern Florida, 1900-2000*. U.S. Geological Survey Circular 1275, Reston, VA, 77.

Restrepo, J.I. et al. 1992. *A Three-Dimensional Finite Difference Ground Water Flow Model of the Surficial Aquifer System, Broward County, Florida*. South Florida Water Management District, West Palm Beach, FL.

Roman, M.R., M.R. Reeve, and J.L. Froggat. 1983. "Carbon Production and Export from Biscayne Bay, Florida." In Temporal Patterns in Primary Production, Seston and Zooplankton. *Estuary Coastal and Shelf Science*, 1:45-59.

Ross, C.A. and W.E. Magnusson. 1989. "Living Crocodilians." In Crocodiles and Alligators, ed. C.A. Ross. Facts on File, Inc., New York, NY, 58–75.

Ross, M.S. et al. 2002. "Multi-taxon Analysis of the 'White Zone': A Common Ecotonal Feature of the South Florida Coastal Wetlands." In The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook, eds. J.W. Porter and K.W. Porter. CRC Press, Boca Raton, FL, 205–238.

Schomer, N.S. and R.D. Drew. 1982. *An Ecological Characterization of the Lower Everglades, Florida Bay, and the Florida Keys*. WS/OBS-82/58.1. Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C.

Serafy J.E. et al. 1997. Effects of Freshwater Canal Discharge on Fish Assemblages in a Subtropical Bay: Field and Laboratory Observations. *Marine Ecology Progress Series*, 160:161-172.

Serafy, J.E., C.H. Faunce, and J.J. Lorenz. 2003. Mangrove Shoreline Fishes of Biscayne Bay Florida. *Bulletin of Marine Science*,72(1):161-180.

Serafy, J. et al. 2008. *Development of Habitat Suitability Models for Biscayne Bay Area Fishes: Assessing Salinity Affinity from Abundance Data*. Final Report. Submitted to the South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1995. *Biscayne Bay Surface Water Improvement and Management (SWIM) Plan – Planning Document*. Planning Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1995. *Biscayne Bay Surface Water Improvement and Management (SWIM) Plan – Technical Supporting Document*. Planning Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2000a. *Lower East Coast Regional Water Supply Plan Planning Document*. Water Supply Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2000b. *Technical Documentation to Support Development of Minimum Flows and Levels for the Caloosahatchee River and Estuary (Draft)*. Water Supply Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2002a. *Technical Criteria to Support Development of Minimum Flows and Levels for the Loxahatchee River and Estuary (Final Draft)*. Water Supply Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2002b. *Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary (Final Draft)*. Water Supply Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2003. *Basis of Review for Water Use Permit Applications within the South Florida Water Management District*. Environmental Resource Regulation Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2006. *Technical Documentation to Support Development of Minimum Flows for Florida Bay*. Watershed Management and Water Supply Departments, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2008. *Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay*. Water Supply Department. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2009. *Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay (including the Final Peer Review Report)*. Water Supply Department. South Florida Water Management District, West Palm Beach, FL.

Shaw, R. et al. 1985. Transport of Larval Gulf menhaden, *Brevoortia patronus,* in Continental Shelf Waters of Western Louisiana: A Hypothesis. *American Fisheries Society,* 114:452–60.

Shine, M.J., D.G.J. Padgett, and W.M. Barfknecht. 1989. *Groundwater Resource Assessment of Eastern Palm Beach County, Florida*. Technical Publication 89-4. South Florida Water Management District, West Palm Beach, FL.

Sklar, F.H. and J.A. Browder. 1998. Coastal Environmental Impacts Brought About by Alterations to Freshwater Flow in the Gulf of Mexico. *Environmental Management*, 22:547–62.

Sonenshein, R.S. 1997. *Delineation and Extent of Saltwater Intrusion in the Biscayne Aquifer, Eastern Dade County, Florida, 1995*. U.S. Geological Survey Water Resources Investigations Report 96-4285, 1 sheet.

Stalker, J., R.M. Price, and P.K. Swart. 2007. *Investigation of Groundwater Flow into Biscayne National Park*. Final Report. Project No. H500000B494, compiled for the U.S. Department of the Interior, Biscayne National Park by the Florida International University and the University of Miami, Miami, FL.

Stoner, A.W. 1983. Distribution of Fishes in Seagrass Meadows: Role of Macrophyte Biomass and Species Composition. *Fisheries Bulletin,* 81(4):837–46.

Sverdrup, Johnson, and Fleming. 1942. “Physical Properties of the Sea Water.” In The Oceans: Their Physics, Chemistry, and General Biology. Prentice-Hall, Inc., New York, NY, 47-74.

Swart, P. and R. Price. 2004. *Biscayne Bay Paleoecological Salinity Study*. Contract No. C-15877. Prepared for the South Florida Water Management District by Rosenstiel School of Marine and Atmospheric Sciences/University of Miami, Miami, FL.

Thayer, G. W., W.J. Kenworthy, and M.S. Fonseca. 1984. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile*. Report No. FWS/OBS-84/02. U.S. Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C., 147.

Torquemada, Y.F., M.J. Durako, and J.L.S. Lizaso. 2005. Effects of Salinity and Possible Interactions with Temperature and PH on Growth and Photosynthesis of *Halophila johnsonii* Eiseman. *Marine Biology,* 148: 251-260.

Trimble, P.J. et al. 2001. “Simulation of the Influence of Climatic Variability on Freshwater Inflow to Florida Bay during the 20th Century.” Abstract. In Proceedings, Florida Bay Science Conference, April 2001, Key Largo, FL.

USACE and SFWMD. 2007. *Comprehensive Everglades Restoration Plan – System-wide Performance Measures*. U.S. Army Corps of Engineers and the South Florida Water Management District. Available from the Everglades Plan Web site at: http://www.evergladesplan.org/pm/recover/eval_team_perf_measures.aspx.

USDOI. 2008. *Ecological Targets for Western Biscayne Bay*. U.S. Department of the Interior.

USDOI. 2008. *Estimates of Flows to Meet Salinity Targets for Western Biscayne Bay*. U.S. Department of the Interior.

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

USFWS. 1999. *South Florida Multi-species Recovery Plan: An Ecosystem Approach*. U.S. Fish and Wildlife Service, Atlanta, GA, 2172.

USFWS. 2001. Florida Manatee Recovery Plan (*Trichechus manatus latirostris*), Third Revision. U.S. Fish and Wildlife Service, Atlanta, GA. 144.

Virnstein, R.W. 1987. "Seagrass-associated Invertebrate Communities of the Southeastern U.S.A.: A Review." In Proceedings of the Symposium on Subtropical Seagrasses of the Southeastern United States, August 1985, Gainesville, FL, 89–116.

Virnstein, R.W. et al. 1983. Seagrass Beds versus Sand Bottoms: The Trophic Importance of their Associated Benthic Invertebrates. *Florida Scientist,* 46:363–81.

Voss, G.L. et al. 1969. *A Report to the National Park Service on the Marine Ecology of the Biscayne National Monument*. Institute of Marine and Atmospheric Sciences, University of Miami, Coral Gables, FL.

Wang, J.D., J. Luo, and J.S. Ault. 2003. Flows, Salinity, and Some Implications for Larval Transport in South Biscayne Bay, Florida. *Bulletin of Marine Science*, 72(3):695–723.

Wanless, H. R., R.W. Parkinson, and L.P. Tedesco. 1994. "Sea Level Control on Stability of Everglades Wetlands." In Everglades: The Ecosystem and Its Restoration, eds. S.M. Davis and J.C. Ogden. St. Lucie Press, Delray Beach, FL, 199–223.

Wingard, G.L. et al. 2004. *Ecosystem History of Southern and Central Biscayne Bay: Summary Report on Sediment Core Analyses - Year 2*. USGS Open-file Report 2004–1312, U.S. Geological Survey.

Wolfert-Lohmann, M.A., et al, 2008. *Science Support Strategy for Biscayne Bay National Park and Surrounding Areas in Southeastern Florida*. USGS Open-File Report 2007–1288, U.S. Geological Survey, Reston, VA, 48.

Woodward-Clyde, Inc. 1998. *St. Lucie Estuary Historical, SAV, and American Oyster Literature Review*. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Zieman, J.C. and R.T Zieman. 1989. *The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile*. Biological Report 85. U.S. Fish and Wildlife Service, Washington, D.C., 155.

Appendix L

PEER REVIEW

ADEQUACY OF TECHNICAL INFORMATION TO SUPPORT MINIMUM INFLOW NEEDS FOR BISCAYNE BAY

Peer Review Facilitator:

Jason Godin, Sr. Environmental Scientist, Water Supply Department

Peer Review Manager:

John Maxted, Senior Supervising Environmental Scientist, Water Supply Department

Project Technical Lead:

Melody Hunt, Lead Environmental Scientist, Water Supply Department

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Florida 33406

Peer Review Panel:

Dr. Paul A. Montagna, Endowed Chair for Ecosystem Studies and Modeling
Harte Research Institute for Gulf of Mexico Studies
Texas A&M University at Corpus Christi
6300 Ocean Drive, Unit 5869
Corpus Christi, Texas 78412

Dr. Ned Smith, Adjunct Scientist
Harbor Branch Oceanographic Institution, Inc.
5600 U.S. Highway 1, North
Fort Pierce, Florida 34946

Dr. Mark S. Peterson, Professor
Department of Coastal Sciences
The University of Southern Mississippi
703 East Beach Dr.
Ocean Springs, Mississippi 39564

Dr. Court Stevenson, Professor
Horn Point Laboratory
University of Maryland Center for Environmental Science
P.O. Box 775
Cambridge, MD 21613-0775

Final Report:
November 13, 2008

PEER REVIEW OF ADEQUACY OF TECHNICAL INFORMATION TO SUPPORT MINIMUM INFLOW NEEDS FOR BISCAYNE BAY

Introduction

The South Florida Water Management District (SFWMD) has requested a peer review of the draft technical document entitled *"Review of Adequacy Of Technical Information To Support Minimum Inflow Needs For Biscayne Bay."* The peer review is being conducted in advance of the development of criteria or a technical approach for water management strategies to meet inflow needs of Biscayne Bay. The District will develop a specific technical approach based upon the input received through the review process.

The purpose of the review is to provide an independent assessment from an expert panel on the adequacy of the available information to support a technical approach to manage minimum inflow needs of natural resources in Biscayne Bay. In addition, the review process provides an opportunity for stakeholders and other interested member of the public to formally contribute to the development of the technical framework. The peer review panel was specifically directed to determine if available information summarized in the project technical report and supporting appendix materials provide a sound scientific basis for the development of a technical approach to support an assessment of minimum inflow needs. The technical report also provides a description of the structure of existing coastal Minimum Flows and Levels technical approaches that may serve as a template for the development of minimum inflow needs for Biscayne Bay.

The peer review panel is composed of four senior scientists: Paul Montagna (chair), Mark S. Peterson, Ned Smith, and Court Stevenson. Together, the panel has complementary expertise in the areas of: marine and coastal ecology, physical oceanography and coastal circulation, hydrology of coastal systems and the contributions of surface and groundwater flows, dynamics of seasonal and year-to-year variation in salinity in coastal systems, biological resources of coastal systems and their sensitivity to salinity variations, and use of watershed and hydrodynamic models for addressing real-world problems in water resource management. None of the panelists have a substantial personal or professional relationship with the SFWMD or any other organization involved in environmental management in Southeast Florida.

The peer review process included review of the technical documents and associated appendices (Table 1) and a workshop (Table 2). The workshop included a field trip to reconnoiter Biscayne Bay on October 27, 2008, a technical workshop where public comment was invited on October 28, 2008, and a public workshop for the panel to begin deliberations on the document on October 29, 2008. In accordance with Florida Sunshine Laws, all communication between panel members regarding the project occurred in person during the public portions of the workshop or via the SFWMD web-board http://webboard.sfwmd.gov/. Specifically, the peer review panel was asked to provide a final report to the SFWMD that addresses questions that accompany the draft technical document (Table 3). The rest of this report is in response to those specific questions.

Peer Review Panel Response to Questions

"Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay"

General

1. *Is the technical information presented in the document and appendices clear? If not, specify the additional information or clarification that would be needed.*

Overall the panel members agreed that this was generally a well written concise document that effectively synthesized the large body of information that was presented in the eleven appendices. Most of the graphics were clear, but a few needed additional editorial attention because axis labels and units were cut off in the transfer from the originals. For example, as we covered in the workshop, the omission of keys on the groundwater Figure 8, in particular leads to some confusion in interpreting the depths of the various aquifers underlying the Biscayne Bay watershed, as well as the meaning of the contours of the Biscayne Bay aquifer. In general, more detailed explanations of the key features in the figures and tables would improve the reader's ability to quickly grasp the material. Also, during our review, we pointed out several omissions of citations mentioned in the text and vice versa – some citations could not be found in the text, and all figures need proper referencing to quickly enable the reader to determine their source. In addition, the use of parallel constructions as well as inconsistent referencing of appendices interfered somewhat with the flow of the document. It would be helpful if references to the appendices appear within each paragraph they support. A list possible editorial emendations is provided in Appendix 1 of this report.

It was also noted that the reference style was inconsistent in terms of formats. One solution to this problem might be to use a bibliographic software package such as Endnote, in which references can be efficiently output in whatever style the editor chooses. The SFWMD could request the inclusion of references in Endnote files as part of the products of literatures searches (e.g., Appendix E, Lewis et al., 2007). In addition, an impressive electronic reference list for Biscayne Bay is available online (http://www.aoml.noaa.gov/general/lib/bbdl.html), which includes 2,259 papers published earlier than 2000 and could provide a foundation for a SFWMD reference file. This list should be brought up to date to reflect recent papers and reports published from 2000 onwards. Also disconcerting to some panel members was the redundancy between chapters 1 and 4 (e.g., Tables 1 and 13), which detracted somewhat from the overall presentation of complex issues and material.

In terms of additional information that would have been helpful for the panel review; there is obviously more information (some published in the scientific literature, and some from local reports) that should be referenced as the minimum inflow needs assessment proceeds. We cite specific information gaps in the sections in our review of Chapter 2 (Hydrology) and Chapter 3 (Biological Resources) below. In addition, several commentators during the public input section at the review (October 29, 2008) also strongly suggested that more information is available and needs to be incorporated into the planning process of Biscayne Bay inflow targets. The panel recommends more effort needs to be made by the SFWMD to solicit more information from the Biscayne Bay technical community, especially since several had participated in the earlier Surface Water Improvement & Management Plans for Biscayne Bay (South Florida

Water Management District, 1988-1989, Surface Water Improvement and Management, SWIM, plan for Biscayne Bay and Appendices A - K. SWIM plan. South Florida Water Management District, West Palm Beach, FL; and South Florida Water Management District, 1995, Biscayne Bay Surface Water Improvement and Management), and are obviously very familiar with the issues.

Despite some gaps and minor flaws in editing mentioned above and listed in Appendix 1 of this report, the panel was impressed with what appears to be a solid effort to begin assembling critical information to formulate the minimum inflow needs for Biscayne Bay and we look forward to its completion in a timely manner. All indications are that, despite the obvious changes in hydrology of the watershed and urbanization in and around Miami, the Biscayne Bay ecosystem has been surprisingly resilient to stress thus far, as evidenced by the large area of intact *Thalassia* beds in the large central portion of the Bay. However, many lagoonal systems are actually delicately poised and can change quickly. Other systems that once supported luxuriant *Thalassia* beds have reached tipping points (as in Florida Bay and several of the Texas bays) resulting in rapid system collapse. Once these systems decline it is often very difficult (and extremely costly) to attempt to bring then back to their former condition. This calls for some urgency on the part of the SFWMD to determine the minimum inflow needs for this estuary as soon as possible.

Hydrology

2a. Are the elements of the existing water budget and watershed inflows (canals, surface water, groundwater and atmospheric) adequate to support the hydrologic analyses presented in Chapter 2?

The elements listed in Appendix A (page 13 in the ECT Final Report of January 2008) include the four inflow terms that one would expect as input in a water budget model for Biscayne Bay (rainfall, canal inflow, ungaged surface inflow and groundwater). Over the course of the workshop, the question of direct storm water runoff was raised and discussed, and it was suggested that this term might be a small contributor of fresh water to the bay. Regardless of its magnitude, it should be noted and discussed. And, given that the model efficiency is lowest at the northern end of Biscayne Bay—where direct storm water runoff would be greatest—this term should be quantified.

It was not clear from the discussions during the panel workshop how, or if, the Atlantic Intracoastal Waterway (AIWW) is handled as a potential source of freshwater inflow at the northern end of the bay. But just as Jewfish Creek is included (“SB2” in Fig. 3.2, p 25 of the January 2008 Final Report, Appendix A) for inflows and outflows to and from Sub-area 8 (Barnes Sound), the AIWW represents a potential conduit for inflows and outflows to and from Sub-area 8 (Snake Creek/Oleta River).

Subsequent to the workshop, ECT supplied additional “Notes on Residence Times” (dated October 30 and posted on the WebBoard November 6). This additional information demonstrates the relative importance of exchange fluxes (Tx) in Biscayne Bay relative to freshwater displacement (Tq). Thus, residence times based on exchange fluxes (Tx), and probably residence times based on both exchange fluxes and the net freshwater supply (T), should be listed and discussed as often as is it necessary to refer to the freshwater displacement time (Tq) in the discussion on page 30 and as a component of Table 5 in the draft technical document, and on page 58 of Appendix A.

2b. Do the mass balance model and analyses presented in Chapter 2 provide an adequate description of related spatial and temporal distributions of salinity within Biscayne Bay and the sub-areas.

Spatial and temporal distributions of salinity are described on page 35 and summarized in Figure 11 and Table 8 (pages 36 and 37 of Chapter 2, the draft technical document). Given that the model can resolve only monthly and longer time scales, the plots in Fig. 11 provide a good visualization of temporal variability of the eight sub-areas. Statistics in Table 8 are the appropriate complement to the analog plots. Figures are not presented to depict spatial variability, but the summary statistics in Table 8 provide a measure of north-south gradients. One gets some sense of wet-dry seasonal differences from Fig. 11, but this measure of temporal variability is not included in Chapter 2 (it appears in Table C.4 of the January 2008 Final Report).

Both Fig. 11 and Table 8 should be interpreted in terms of the error statistics, which do not appear in Chapter 2. These statistics are included in Appendix A, and it is there that one learns that the results plotted in Fig. 11 and listed in Table 8 are accompanied by "error bars" of ±1-2 psu.

For the purpose of describing spatial distributions, the eight sub-areas provide very general information. It was noted during the panel workshop that the decision to use eight sub-areas came from a cluster analysis of hydrographic data. But a larger number of sub-areas (at a different "cluster level") would produce a more refined picture of the subtle salinity gradients in the study area, and would be useful to planning of future spatial inflow needs.

It is also evident from the information contained in Appendix C and presented in the public comments, that there is a gradient of salinity from west to east, because freshwater input is derived from land on the west and mixes with oceanic water toward the east. These salinity gradients are homogenized and cannot be resolved in the sub-area water budget approach, which is based on subareas along a north-south axis. If the salinity is important in the future minimum flow rule development process, then using a hydrodynamic model to predict salinity gradients east-west, as well as north-south, will be important.

3. Does the analysis presented in Chapter 2 sufficiently describe the sensitivity of maximum and minimum salinity values to the freshwater inputs for each sub-area, including inflows (canal inflow and groundwater)?

The sensitivity of salinity to freshwater inputs is described on page 37 and shown graphically for all sub-areas in Figs. 12-14 (there is no figure to complement Fig. 14 by showing sub-areas in which *minimum* salinity responds to total watershed inputs, etc.). These three figures include *one-year* time lags. It would be appropriate to repeat the calculations with *six-month* lags that average inflows over the preceding wet or dry season. The maximum salinity in a given dry season, for example, is probably more sensitive to conditions averaged over the preceding wet season than to conditions averaged over the preceding year. The freshwater residence times for Biscayne Bay (which is not the freshwater displacement, as described in page 30) suggest that the bay's "hydrographic memory" does not extend back more than several months for most of the eight sub-areas. One approach for quantification of lag times would be a comparison of the continuous salinity data recorded in recent years by the Biscayne Bay National Park (see their posting on the web board) with inflow data.

The investigation of sensitivity does not seem to go beyond establishing that the coefficients are significantly different from zero (this is described in Appendix A). If there is any way to quantify degrees of sensitivity, this would be useful for describing what is most and least important in producing extreme salinity values.

4. *Which, if any, of the sub-areas would be suitable for further development of area-specific links between inflows and salinity?*

The most recent measures of model performance (Table 3.3, page 30 in "Update to the Final Report," September 2008) suggest that the northern, highly urbanized part of the Biscayne Bay study area should get some additional attention. There, the model efficiency is lowest, the average absolute error is largest, and two possible sources of fresh water—storm water runoff entering the bay directly and the freshwater component of AIWW inflows and outflows—have not been quantified. The dynamics of the northern part of the bay may differ significantly from those controlling salinity elsewhere in the bay. If so, then modified versions of Equations 3.2 and 3.3 (in Appendix A) may be needed to simulate salinity extremes adequately.

Biological Resources

5. *Does Chapter 3 and the referenced material including appendices, provide an appropriate description of existing biological resources for each sub-area and for Biscayne Bay as a whole?*

Chapter 3 provides an overview and list of the charismatic and larger organisms in the Biscayne Bay system; however there is very little exposition of the spatial and temporal dynamics of any species. For example, there are only two distribution maps of species in Chapter 3 (*Thalassia testudinum* and *Halodule wrightii*). Although it was not entirely clear in the technical document, both maps are presumably based on a portion of the Miami - Dade Department of Environmental Resource Management (DERM) data set, which begins in 1999 and runs to present. One problem emerges because the two maps are plotted on two very different scales. It would be much more comprehensible to present them on the same spatial scale. Also there is the same bay-wide coverage for *Syringodium filiforme* in the DERM data set and it would be advantageous to present all three species alongside one another for easy comparison. It would also be nice to have a map of the bay showing salinity at least during wet, dry, and average years for further comparison. Perhaps even more disappointing was the lack of spatial plotting of any other species mentioned in the text and that no attempt was made to analyze consumer changes over space or time (related to inflow and salinity patterns in the bay).

It is of course very difficult, if not impossible, to describe even rudimentary dynamics of a large number of species, so some level of indicator selection must occur. This might be best accomplished in a facilitated workshop where all the stakeholders are invited. Then a focused analysis of the indicators can be performed. Several species were mentioned as potential candidates for valued ecosystem components (VEC) during our review beyond *Halodule* and *Thalassia* including Pink Shrimp, Snook, Oysters and Crocodiles. However, community analyses are more likely to be useful rather than a species-based approach and we agreed that even a salinity zone could constitute a VEC.

There were significant information gaps that need to be filled. The panel was particularly troubled about the omissions of any reference to the benthos in this lagoonal system. Benthos are largely immobile and are often excellent indicators of system stress including salinity changes. The omission of benthic organisms is puzzling because the Biscayne Bay Literature Review cited above contains over 40 references pertaining to the benthos in the Bay. It would be an obvious next step to look these over and see what relationships to salinity can be derived. Also, past efforts by EPA as part of the national EMAP assessment (http://www.epa.gov/emap/) may contain more recent information on Biscayne Bay. Although seagrass is highlighted in the technical document, an important recent paper was not included (Lirman et al., 2008, "Seasonal changes in the abundance and distribution of submerged aquatic vegetation in a highly managed coastal lagoon," *Hydrobiologia* 596:105-120) and should be considered in future analysis of salinity impacts on submersed aquatic vegetation (SAV) along the western edge of the Bay. Another paper, unfortunately not highlighted in the technical document (but reviewed in appendix F) is Kahn and Durako published in 2006 in the *Journal of Experimental Marine Biology & Ecology* 335:1-12, which provides a critical threshold range of salinity tolerance (30 - 40 psu) for *Thalassia* seedlings. This information could be very useful for establishing inflow needs into Biscayne Bay if *Thalassia* is selected as a VEC in a future technical approach.

During the review, the panel emphasized the importance of SAV as a foundation species in Biscayne Bay because of the tight linkage of the plants with the biogeochemistry of sediments. Foundation species create habitat and structure in ecosystems. *Thalassia* is known for its extensive rhizomatous matrix in the surficial sediments, which can produce a complex, convoluted, aerated zone where nitrification produces nitrate. Nitrate is highly mobile and can be subsequently denitrified when it migrates to a deeper anoxic zone or when the root zone becomes more anoxic at night. The enhancement of tightly coupled nitrification and denitrification is especially helpful in removing excessive nitrogen, which enters estuaries from agricultural and municipal waste water. In addition, a rich supply of oxygen transported from SAV shoots into roots and rhizomes eventually leaks out into surrounding sediment, helping to oxygenate adjacent micro-zones, keeping hydrogen sulfide levels low. Low sulfide helps promote a well diversified benthos and reduces the potential for damage to meristematic tissues of roots and rhizomes, producing a more stable SAV community. Although all species of SAV can help oxygenate sediments to some extent, *Thalassia* has a higher "below-ground to above ground ratio" and thus is generally more effective at influencing the sediment biogeochemistry compared to weakly-rooted *Halodule* (or *Ruppia*). The *Thalassia* panel members observed in Biscayne Bay was dense in front of the Burger King site, but there were abundant epiphytes on the leaves at this location. This could be an indicator of future problems if they effectively reduce photosynthesis, forcing the system towards a tipping point. There is now worldwide concern that seagrasses have generally declined in response to anthropogenic perturbations and hopefully Biscayne Bay can be kept off the global list of systems in decline.

There are obvious complications in Biscayne Bay because of the supply of freshwater adjacent to the mangrove zone and in isolated areas where there are still functional freshwater springs in the Bay. Because of its tolerance for low salinity, *Halodule* is better adapted to these areas and could be considered an indicator for adequate freshwater inflow. Whereas the north-south gradient was emphasized in the technical document, the panel was even more impressed with the east-west gradient, which potentially has important ramifications for seagrass and the invertebrate community. As mentioned earlier, it would be helpful for the technical document to include more isohaline gradient data for the Bay whereby some of the relationships between flow, salinity and biological resources could made more evident. Although the box model approach has undeniable strengths in terms of overall hydrological budgets, the addition of hydrodynamic modeling would be useful for predicting how much flow is necessary to maintain the salinity gradients in the estuarine zone where smaller spatial scales and shorter time scales have to be investigated. The hydrodynamic model for Biscayne Bay, developed by J. D. Wang and his colleagues over the last several decades (e.g., Wang al., 2003, "Flows, Salinity, And Some Implications For Larval Transport In South Biscayne Bay, Florida," *Bulletin Of Marine Science* 72(3): 695–723, 2003), is apparently regarded as "state-of-the art" and along with other groundwater driven models developed by the Army Corps, could provide more information on the dynamics of salinity shifts in Biscayne Bay.

6. *Is the biological resource information sufficient to determine short-term (e.g., 2 years) and long-term (e.g., irreversible) impacts <u>(by salinity changes that could be induced by low flow)</u> to the resource? If not, what information is still needed, and do the information needs vary depending on location within the Bay? <u>(Underlined added as a clarification at the workshop.)</u>*

To determine short- or long-term change in abundance or distribution of biological resources, there must be a baseline understanding of the spatial and temporal dynamics of the species of interest. At a minimum, the information required would be a species distribution map and some information on recent trends of the temporal dynamics. This minimal information needed to identify short- or long-term trends with respect to salinity change is a very high standard, and it is not clear that such data exists for many species.

This kind of information appears to be available from DERM for some seagrass species because they have been performing annual surveys. The DREM information was not well documented in the technical document. Overall, very little information is provided in the technical document about spatial and temporal dynamics, and none is provided for any species in a consumer guild.

The most important drivers of change in mangrove or seagrass distribution and abundance may by climate change for both short- and long-term scales, because of change in wet and dry cycles or sea-level rise. The Mangrove fringe is the main estuarine habitat, and could be threatened by future changes in development as well.

For mangrove and seagrass species, short-term impacts could be important if there are effects on seeding recruitment. An understanding of the life cycle of these plants is important.

One interesting and unique attribute of the Biscayne Bay system are the white zones. These can be indicators of change caused by salinity changes in the groundwater, salinity intrusions, or salinity in the tidal surface waters. An important question is whether mangroves dying and being replaced by the white zone?

In order to detect impacts of future projects or regulatory changes, it is important to select an indicator species, assemble base-line data sets, perform follow-up monitoring, and then perform change analyses. The indicators do not have to be species, but can also be a habitat or assemblage, such as seagrass beds. The baseline, however must have both spatial and temporal data available. In addition, there must also be ancillary data about water quality, sediments, and hydrography in order to distinguish between potential multiple stressors. A monitoring program is also essential for adaptive management in order to know if the management strategies are working as anticipated. Combining monitoring and existing data to detect change over time can only occur using a "Before versus After, Control versus Impact" (BACI) sampling design. The critical test in a BACI design is the interaction between time and location, because impact occurs only if the change over time is different in the impact area compared to a control area. It is always difficult to define or find control or reference sites, and to justify sampling outside the impact zone. However, power to detect change is very poor for unbalanced sampling designs, so the tendency to skimp on control sites must be resisted.

7. *Are there additional valued ecosystem components (VEC's) or indicator species that should be considered that provide a resource-salinity link? Would these indicator species or VEC's be the same throughout the Bay or does existing information indicate that they might vary depending on location within the Bay?*

It is extremely difficult and problematic to manage ecosystems based on a single species concept. Ecosystem-based management strategies appear to be more useful and appropriate, particularly in a system as complex and urbanized as Biscayne Bay. In developing such an approach it is recommended that the district develop a stakeholder-based process to choose a VEC based on cultural, ecological, economic, aesthetic, and use values because the VEC and indicators may in fact be different. You are looking for sentinels in the system to allow for development of adaptive management scenarios. An ecosystem-based approach is important because not all indicators are charismatic or a VEC; thus, examination of metrics like community assemblage structure and diversity spatially and temporally are important system integrators as well as estuarine-dependent species, which are vital to a more full understanding of system integrity and sustainability. The latter species also require a consistent salinity gradient to be established (see below discussion) for this to be meaningful.

During the presentation, it was stated that stationary habitats (at fixed locations), such as the vegetated communities, are easier to measure than pelagic habitats. In addition, data on benthos are also easier to interpret. So it is surprising that no information on animal benthos dynamics is presented. Thus, it appears that taking a critical look at benthic invertebrate community structure and diversity data would be a great start because these taxa are fixed in place, relatively long-lived, and a link to important higher trophic levels, such as fish. Also, benthos abundance, biomass, and diversity can be quantified and mapped at various temporal scales and spatially both east-west and north-south within Biscayne Bay. Benthic communities are also well known to be very sensitive to salinity gradients so are ideal sentinel species.

Technical Approaches

8. *Describe the strength and weaknesses of the three technical approaches (flow-based, condition-based, and resourced-based) discussed in Chapter 4 for potential application in developing inflow criteria for Biscayne Bay?*

Coastal and estuarine ecosystems are structured by a series of hierarchical and nested processes (abiotic and biotic) that influence organisms and culminate in a system that is connected and linked spatially and temporally. The three approaches (illustrated in Figure 17) in the draft Biscayne Bay document are not really three different approaches because they are actually a cascade of one environmental process that defines the habitat of the resource of interest. It is clear from detailed discussion at the meeting that Figure 17 and associated text needs to be modified to better reflect this reality. For example, the orange arrows need to be deleted entirely and text in the legend and document text need to clearly point out that the blue arrows reflect the processes that are vital to establishment of the estuarine resources box whereas the green arrows reflect potential management scenarios. This will make the discussion reflect ecological reality and allow the district to provide adaptive management scenarios that link to estuarine resources.

The strength and weaknesses of the specific approaches are:

- The flow-based approach likely is inappropriate for Biscayne Bay because it is highly altered with watershed development, and components (locations) are tidally driven to some various degrees.
- The condition-based approach is important only in context to the VEC or indicator chosen, unless you choose to use salinity as a condition. However, you have to be careful about confounding water quality factors (salinity) and circular reasoning because the draft document does not consider tidal freshwater through polyhaline salinity zones relative to habitat use by species of importance or life stages of those species as would be required for such an approach to be meaningful. The current use of the box model approach will not be discriminating or realistic enough to address the salinity zones noted above. It appears that you are really using a resource-based approach and just calling it something else. Flow, condition, resource-based approaches are linked in a cause and effect way as noted above.
- For Biscayne Bay, you might consider the state of the VEC as a condition that can drive an indicator by providing foundation habitat for that indicator. Examples might be oysters or species of submerged aquatic vegetation, which vary in abundance across salinity zones.
- Although they are all likely one and the same, in the end, the resource-based approach likely to be the most fruitful. You can use the chosen VEC or indicator as an end-point.

9. *Is there sufficient scientific support for defining inflow criteria based upon periods of hypersalinity within estuarine portions of any of the 8 sub-basins? Specify potential*

> *analyses that could establish measurement thresholds, seasonality, duration, and frequency, and the general locations where monitoring might be proposed.*

Hypersalinity is very likely a key concern for Biscayne Bay, and preventing or ameliorating existing hypersalinty can be a very important management goal. There are two key reasons why this is so. 1) Biscayne Bay is actually a lagoon and not a classic estuary, and 2) hypersaline environments are very unstable and at the edge of tipping points, such that they are subject to sudden and rapid regime shifts.

Recognizing the type of ecosystem that is present is very important in order to choosing a successful management strategy. Common names, such as bay or lagoon, do not have a clear definition. Is it not common for members of the general public to ask: what is the difference between a bay and an estuary? The technical definitions however are very important. The water budgets and salinity distributions show that Biscayne Bay is not a classic estuary where there is one large dominant freshwater source and a strong salinity gradient from the mouth of a river to the inlet of the sea. Instead, there are multiple smaller sources of freshwater that flow into a large, shallow, semi-enclosed marine-like bay. The salinity gradients of Biscayne Bay are almost diffuse with freshwater hugging shorelines and salinity isohalines generally running parallel to the shore, not perpendicular to it. The overall average salinity is high and at marine levels, and that is the first clue that something unusual is going on. How can there be constant flow into the bay and the salinity is still nearly oceanic? It is because evaporation is exceeding inflow in the sub-tropical, broad, shallow lagoon with a large surface area. This means that even a small change in flow can have huge consequences on bay salinity. The water budgets are enormously useful in this context because you can easily calculate the amount of inflow you need to offset evaporation, even in dry years.

Hypersalinity is very dangerous for the simple reason that it is rare. There are only five hypersaline estuaries in the world, and their total surface area is quite small. Because hypersalinity is rare, estuarine organisms are adapted to live between freshwater and marine conditions. There are likely microorganisms that are specifically adapted to hypersaline environments, but there are no known multicellular plants or animals with such characteristics. Consequently, the communities of hypersaline estuaries are a subset of the larger estuarine communities because only those that can tolerate hypersalinity will survive. Survival is not the same as thriving. The consequence is a low-diversity community that is under stress, and perhaps suffering sublethal effects, such as low growth or reproductive rates. These low diversity communities are highly susceptible to perturbations and are not stable during times of stress, such as prolonged drought, freezes, nutrient loading, low-dissolved oxygen, or chemical pollution.

The best example on how a hypersaline lagoon can suffer a sudden regime shift, is what happened in Laguna Madre, Texas in the 1990’s. Much like Biscayne Bay, Laguna Madre is broad, long, shallow, hot, very salty, and has little inflow. In December 1989, a freeze killed millions of fish, and the ensuing decomposition released enough nitrogen (from fish flesh) into the water to sustain a brown tide bloom for more than a decade. The once clear lagoon was turned into a highly turbid system and the shading stressed seagrass leading to low productivity, death, species displacement, and habitat loss. The chlorophyte responsible for the bloom was previously unknown in Laguna Madre, but it was uniquely tolerate of high salinity and preferred ammonia over nitrate as a nitrogen source. The ammonia was the dominant source of nitrogen and was derived from decaying fish and invertebrate corpses. The chlorophyte was also indigestible for most zooplankton and the pelagic larvae of marine benthos. The consequence was an ecosystem crash that lasted nearly 20 years. The lesson is that low diversity systems are unstable because weeds can dominate rapidly and change the trophic structure rapidly leading to regime shifts.

Another consequence of hypersalinity in warm waters is very low dissolved oxygen (DO) saturation. The solubility of DO decreases with increasing salinity and increasing water temperature. Because hypersalinity is exacerbated in warm water, an important confounding interaction with water quality must result. In fact, in hot, salty water, 100% DO saturation can occur as low as 4 mg/L, much below the accepted water quality standard of 5 mg/L. This leads to additional stress, which is a classic problem of multiple stressors. Another consequence is that hypoxia (low DO levels) conditions can occur at higher levels. For example, the accepted definition of hypoxia is 2 mg/L, but it has been show that when Corpus Christ Bay, Texas is hypersaline, hypoxia effects start at 3 mg/L. Because the saturation is already low to in hypersaline waters, this high level of stress means that the communities are constantly under stress even during normal conditions.

For hypersalinity to be managed, it will be necessary to determine the extent and duration of the periods of hypersalinity. Although salinity trends are the subject of Appendix C, there is very little about this in the current report, this is an important data gap to fill. The water budget approach will have to be supplemented with hydrodynamic salinity models to identify where hypersalinity is likely to occur, over what duration, and how frequently. Then, some indication of the tolerance of the existing community will have to be assessed. But, remember the lessons of Laguna Madre, and be aware that sudden regime shifts will occur under stress from multiple sources.

10. *Are there other technical approaches or methods that should be considered that have been applied to establish freshwater inflow requirements in highly modified/urbanized coastal lagoon systems like Biscayne Bay in the USA or in other parts of the world?*

As outlined in the technical document all approaches used for developing flow criteria fall into one of three categories: inflow-based, condition-based, or resource-based. These are the essential elements of the Alber model as described in Figure 17. There are two other approaches that the panel is aware of. One is the value-based approach used in South Africa (Adams et al., 2002, "A Method To Assess The Freshwater Inflow Requirements Of Estuaries And Application To The Mtata Estuary, South Africa," *Estuaries* 25: 1382-1393). This particular value-based approach is not likely useful in the U.S. because South Africa has very unique water laws based on the concept that water is first reserved for the environment. The second is the governance-based approach (Olsen, S.B., T.V. Padma and B.D. Richter, 2007, "*Managing Freshwater Inflows To Estuaries: A Methods Guide,*" U.S. Agency for International Development, Washington, D.C. http://www.nature.org/initiatives/freshwater/files/methodsguidev61.pdf). The governance approach involves negotiation of plans and policies and subsequent decision making, monitoring, education, and enforcement. Like the South African values-approach, the governance-approach relies on the values, beliefs and views of individuals and groups. The values- and governance- approaches use, but are not necessarily driven by, technical information.

There is a slight circularity in the Alber model and this is captured in the arrows which connect every box to one another in all directions. In essence there really are only two approaches: flow-based and resource-based, because it is possible to simply choose a percent reduction in flow as has been done in some circumstances. More common, however, is choosing a resource-based approach where salinity requirements (or tolerance limits for the case of hypersaline conditions) of a desired VEC or indicator resources is first chosen, and then a hydrodynamic model is used to predict flow conditions that would give rise to the desirable salinity distributions to meet the requirements or tolerances of the VEC or indicator species. In this sense, one starts in the farthest right box of Figure 17 and used the green arrows only.

One issue facing management of resources is that the “best available science” is just that and nothing more. There is never certainty in ecology because of the enormous complexity and inherent variability of coastal ecosystems. Thus, in addition to the Alber model, it is important to include adaptive management. This is simply a process where monitoring accompanies reassessment over time. For example in Texas, there is usually a Technical Advisory Group (TAG) to help identify data sources, review recommended inflow regimes, and participate in monitoring that is then used in an adaptive management framework. The data and public input can then be used to choose a VEC, sentinel species, or group of species. Stakeholder input has already improved the process for Biscayne Bay as can be seen by the large sets of new information posted on the WebBoard.

The Alber model lacks some detail. For example, an inflow regime has components of timing, frequency, duration, and extent (or magnitude) of flows necessary to sustain or protect the chosen VEC, sentinel species, or group of species. Each of those four components can be varied such that potential inflow regimes are quite numerous. However, in the case of a lagoon such as Biscayne Bay, there will be quite a bit of uncertainty, and thus monitoring to determine if targets are met and if resources respond in the expected way will be critical. This monitoring will be critical in the context of adaptive management

One other new and interesting approach is the just released draft guidelines for the LCRA-SAWS water project in Texas (http://lcra.org/lswp/index.html). The proposed guidelines, which were released October 31, 2008 and are under review, recommend a complete inflow regime for the Colorado River with different targets for different climatic conditions (http://lcra.org/lswp/news/2008_1031.html). The method used was the Alber model, where sentinels were chosen, salinity requirements were identified, and hydrodynamic models were used to predict salinity under different inflow regimes. The new approach is using four different inflow regime criteria over the long-term to maintain bay health during periods of drought.

Table 1. Documents reviewed by the peer review panel.

Type	**Name**
Document	Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay
Appendix A	Environmental Consulting and Technology, Inc. Hydrology Report, January 2008 and September 2008 Update
Appendix B	Flow and Ecological Targets for Biscayne National Park
Appendix C	Salinity Observations
Appendix D	Barnes, Ferland and Associates, Inc. Report, 2004a
Appendix E	Lewis Environmental Services, Inc. Report, 2007
Appendix F	Summary of Biscayne Bay Coastal Wetlands Investigations, SFWMD, 2004-2007
Appendix G	Serafy Report, 2008
Appendix H	Example Analyses to Link Salinity with Inflow and/or Water Level
Appendix I	Description of Miami-Dade County Drainage Basins
Appendix J	Conceptual Ecological Models
Appendix K	Technical Documentation to Support Development of Minimum Flows and Levels for Florida Bay

Table 2. Workshop agenda.

WORKSHOP AGENDA

Independent peer review of the adequacy of technical information to support minimum inflow needs for Biscayne Bay.

October 28-29, 2008

Rosenstiel School of Marine and Atmospheric Science Auditorium
4600 Rickenbacker Causeway, Miami, Florida 33149-1098

TUESDAY, OCTOBER 28

8:30 AM	Welcome and overview of expectations for the workshop ▪ John Mulliken, Water Supply Planning Division Director, SFWMD ▪ John Maxted, Peer Review Manager, SFWMD ▪ Paul Montagna, Peer Review Chairperson, Harte Research Institute for Gulf of Mexico Studies at Texas A&M University- Corpus Christi
9:00 AM	Technical presentation ▪ Melody Hunt, Lead Scientist, SFWMD
9:30 AM	Panel questions of the SFWMD technical team ▪ Paul Montagna, Peer Review Chairperson, Harte Research Institute for Gulf of Mexico Studies at Texas A&M University - Corpus Christi ▪ Mark Peterson, University of Southern Mississippi, College of Marine Sciences ▪ Ned Smith, Harbor Branch Oceanographic Institute ▪ Court Stevenson, University of Maryland, Horn Point Laboratory
10:00 AM	Break
10:15 AM	Continuation of questions to SFWMD technical team
12:00 PM	Lunch Break
1:00 PM	Continuation of questions to SFWMD technical team
2:15 PM	Break
2:30 PM	Public comments
4:30 PM	Adjourn

WEDNESDAY, OCTOBER 29

8:30 AM	Panel discussion of SFWMD peer review questions
10:30 AM	Break
10:45 AM	Panel discussion on development of the final report
11:30 PM	Lunch Break
12:30 PM	Panel discussion on development of the final report
2:30 PM	Adjourn

Table 3. Questions provide to the peer review panel by the SFWMD.

"Adequacy of Technical Information to Support Minimum Inflow Needs for Biscayne Bay"

General

1. Is the technical information presented in the document and appendices clear? If not, specify the additional information or clarification that would be needed.

Hydrology

2. a. Are the elements of the existing water budget and watershed inflows (canals, surface water, groundwater, and atmospheric) adequate to support the hydrologic analyses presented in Chapter 2?

   b. Does the mass balance model and analyses in Chapter 2 provide an adequate description of related spatial and temporal distributions of salinity within Biscayne Bay and the sub-areas?
3. Does the analysis presented in Chapter 2 sufficiently describe the sensitivity of maximum and minimum salinity values to the freshwater flow inputs for each sub-area, including inflows (including canal inflow and groundwater)?

4. Which, if any, of the sub-areas would be suitable for further development of area – specific links between inflows and salinity?

Biological Resources

5. Does Chapter 3 and the referenced material including appendices, provide an appropriate description of existing biological resources for each sub-area and for Biscayne Bay as a whole?

6. Is the biological resource information sufficient to determine short term (e.g. 2 years) and long term (e.g. irreversible) impacts to the resource? If not, what information is still needed, and do this information needs vary depending on location within the Bay?

7. Are there additional valued ecosystem components (VEC's) or indicator species that should be considered that provide a resource-salinity link? Would these indicator species or VEC's be the same throughout the Bay or does existing information indicate that they might vary depending on location within the Bay?

Technical Approaches

8. Describe the strength and weaknesses of the three technical approaches (flow-based, condition-based, and resourced-based) discussed in Chapter 4 for potential application in developing inflow criteria for Biscayne Bay?

9. Is there sufficient scientific support for defining inflow criteria based upon periods of hypersalinity within estuarine portions of any of the 8 sub-basins? Specify potential analyses that could establish measurement thresholds, seasonality, duration, and frequency, and the general locations where monitoring might be proposed.

10. Are there other technical approaches or methods that should be considered that have been applied to establish freshwater inflow requirements in highly modified/urbanized coastal lagoon systems like Biscayne Bay in the USA or in other parts of the world?

Appendix 1. List of recommended editorial changes for the technical document.

P. vi, line 12 of the Executive Summary: "shows" should be replaced by "show."

P. 17, Fig. 8. What do the lines represent?

P. 20, 2nd line from bottom in Chapter 2: "discusses" should be replaced by "discuss," because of the et al. following Enfield.

P. 26, line 11: "has" should be "have."

P 28, line 2: "has" should be "have" because of the et al. following Wang.

P. 31, Table 4: Change the "103s" to "1000" as you did in Table 5?

P 38, line 4: "confirm" and "show" should become "confirms" and "shows."

P. 39 -41: For Figs. 12-14, it would be useful to reference Fig. 10 as a key for the geographic colors.

P. 56 & pg 77: - *B. chrysura* is *B. chrysoura*.

P. 58: *Atherinidae* has been changed to *Atherinopsidae*.

P. 96: *L. rhomboids* is *L. rhomboides*.

General Comment: ppt and psu are used interchangeably in different places. The accepted practice is to use psu for measurements by sonde or refractometer, but this is not critical. Regardless, please be consistent throughout the document.

sfwmd.gov

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Florida 33406
561-686-8800 • FL WATS 1-800-432-2045
www.sfwmd.gov

MAILING ADDRESS: P.O. Box 24680
West Palm Beach, FL 33416-4680