

**

DRAFT

Proposed Minimum Water Level Criteria for Lake Okeechobee, the Everglades, and the Biscayne Aquifer within the South Florida Water Management District

Prepared by SFWMD Staff:

Department	Participant	Role/Responsibility
Planning	David Swift	Everglades
Planning	Jeff Giddings	Biscayne Aquifer
Ecosystem Restoration	Karl Havens	Lake Okeechobee
Planning	Joel VanArman	Document Production
Office of Counsel	Cecile Ross	Legal Issues
Regulation	Scott Burns	Regulatory Issues

South Florida Water Management District
West Palm Beach, Florida
May 12, 1998

Draft Minimum Water Level Criteria - May 12, 1998

Proposed Minimum Water Level Criteria for Lake Okeechobee, the Everglades, and the Biscayne Aquifer

Table of Contents

I. INTRODUCTION	1
A. LEGAL BACKGROUND	1
B. PROCESS FOR ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS	2
1. Process Steps and Activities.	2
2. Scientific Peer Review.	3
C. MFL RECOVERY AND PREVENTION STRATEGY.	4
D. DESCRIPTION OF PRIORITY WATER BODIES	4
1. Lake Okeechobee.	4
Major Features.	4
Water Resource Issues.	6
Water Management Features.	7
Lake Regulation Schedule.	7
Drought Management.	8
2. The Everglades.	10
Major Features.	10
Water Resource Issues.	11
The Water Conservation Areas (WCAs).	12
Water Conservation Area 1.	12
Physical Characteristics:	12
Management Issues:	12
Water Conservation Areas 2A and 2B.	13
Physical Characteristics:	13
Management Issues:	13
Water Conservation Areas 3A and 3B	14
Physical Characteristics:	14
Management Issues:	14
Holeyland and Rotenberger Wildlife Management Areas.	15
Physical Characteristics.	15
Major Issues.	15
Everglades National Park	15
Physical Characteristics.	15
Major Issues.	15
Shark River Slough.	16
Physical Characteristics:	16
Management Issues:	16
Southern Marl-Forming Marshes.	17
Physical Characteristics:	17
Management Issues:	17
3. Coastal Biscayne Aquifer	17
Major Features.	17
Major Issues.	19
E. ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS	20

Draft Minimum Water Level Criteria - May 12, 1998

1. Water Resource Functions	20
Water Resource Definition	20
Lake Okeechobee.	21
The Everglades.	22
Biscayne Aquifer.	22
2. Identification of statutory "Considerations" and "Exclusions"	22
"Considerations."	23
"Exclusions."	23
 F. WATER RESOURCE CONSIDERATIONS	24
1. Lake Okeechobee	24
2. Water Conservation Areas	25
3. Holey Land and Rotenberger Wildlife Management Areas	26
4. Everglades National Park	26
5. Biscayne Aquifer	27
 G. LEVEL OF PROTECTION PROVIDED BY "SIGNIFICANT HARM" STANDARD	27
1. Consumptive Use Permitting Role: Harm Standard	28
2. Water Shortage Role: Serious Harm Standard	28
3. Comparing Significant Harm to Permit & Water Shortage Standards	28
 H. DEFINITION OF SIGNIFICANT HARM TO WATER RESOURCES	29
 II. METHODS	30
A. METHODS USED TO DEVELOP MFL CRITERIA FOR LAKE OKEECHOBEE ..	30
1. Historical Water Levels.	30
2. Review of Drought Management Plans for Lake Okeechobee.	30
3. GIS Studies.	30
4. Recent Ecological Research.	31
B. METHODS USED TO DEVELOP MFL CRITERIA FOR THE EVERGLADES	31
1. Literature Review.	31
2. Review of Historical Water Levels and Fire Records.	31
3. Modeling.	32
C. METHODS USED TO DEVELOP MFL CRITERIA FOR THE BISCAYNE AQUIFER	33
1. Literature Review.	33
2. Data Analyses and Modeling Approaches.	33
 III. RESULTS -- PROPOSED MINIMUM FLOWS AND LEVELS CRITERIA	37
A. PROPOSED MFL CRITERIA FOR LAKE OKEECHOBEE	37
1. Technical Relationships that Equate to Significant Harm	37
Relationship Between Lake Levels and Water Supply.	37
Drought Management.	37
Protection of the Coastal Aquifer.	38
Water Supply to the Lower East Coast.	39
Water Supply to EAA, Caloosahatchee and St. Lucie Basins	40
Water Supply for Everglades National Park.	40
Relationship of Lake Levels to Protection of Ecological Resources	40
Importance of the Littoral Zone.	41
Relationship of Lake Stage and Littoral Zone Flooding and Drying	42
Expansion of Introduced Exotics	42

Draft Minimum Water Level Criteria - May 12, 1998

Increased Frequency of Fire.	42
Response of Littoral Zone to Historical Water Levels.	44
Relationship of Lake Stage and Navigation/Recreation Access. .	46
2. Proposed Criteria	46
Minimum Water Depth:	47
B. PROPOSED MFL CRITERIA FOR THE EVERGLADES	47
1. Technical Relationships that Equate to Significant Harm.	48
Relationship of Ground Water Levels to Everglades Soils.	48
Everglades Water Levels and Soil-Plant Community Relationships.	48
Peat Formation and Soil Loss in the Everglades.	48
Marl Deposition.	52
Effects of Low Water Levels on Everglades Plants and Wildlife.	52
Reduction in Primary Productivity.	53
Changes in Distribution and Abundance of Plants.	53
Changes in Wildlife abundance and Distribution.	53
Effects of Water Levels on Fires.	53
Effects of Fire in the Everglades.	53
Fire History.	54
2. Proposed MFL Criteria.	54
Selection of Soils as the Basis for Establishing Minimum Levels: ..	54
Definition of Terms:	56
Criteria for Protection of Peat Soils and Associated Wetlands: ..	56
Criteria for Protection of Marl Soils and Associated Wetlands: ..	57
C. PROPOSED MFL CRITERIA FOR THE BISCAYNE AQUIFER	60
1. Technical Relationships that equate to Significant Harm	60
Relationship between Ground Hydrology and Saltwater Intrusion.	60
Ghyben-Herzberg Relationship.	61
Comparison with Other Studies.	61
Theoretical versus Actual Position of the Saltwater Interface.	62
Aquifer Water Level/Water Quality Relationships.	62
Maintenance of Canal Stages to Control Saltwater Intrusion. ..	65
Evaluation of Coastal Canal Stages	66
Localized Salt Water Intrusion Modeling.	66
2. Proposed MFL Criteria.	68
Surface and Ground Water Flows in South Dade County, Florida.	69
IV. CONCLUSIONS AND RECOMMENDATIONS	71
A. CONCLUSIONS AND RECOMMENDATIONS FOR SPECIFIC RESOURCES ..	71
1. Lake Okeechobee.	71
Minimum Level	73
2. The Everglades	73
3. Coastal Biscayne Aquifer.	74
B. GENERAL RECOMMENDATIONS	76
V. LITERATURE CITED	77

Draft Minimum Water Level Criteria - May 12, 1998

List of Figures

Figure 1.	Priority Areas for Establishing Minimum Flows and Levels	5
Figure 2.	Lake Okeechobee Regulation Schedule "Run 25"	8
Figure 3.	Hydrologic and Physiographic Provinces of the ENP Study Area.	16
Figure 4.	Location and Extent of the Biscayne Aquifer System in South Florida.	18
Figure 5.	Ghyben-Hertzberg relationship showing freshwater/saltwater interface along the LEC.	20
Figure 6.	Conceptual Relationship among the Terms, No Harm, Harm, Significant Harm and Serious Harm	29
Figure 7.	SFWMD coastal canal network indicating key canals and structures for maintenance of minimum levels in the Biscayne Aquifer.	35
Figure 8.	Lake Okeechobee Water Supply Management Zones	38
Figure 9.	Amount of water available in Lake Okeechobee	39
Figure 10.	Exposed land (dark gray areas) in marsh zones and percentage of total marsh exposed for six water level conditions in Lake Okeechobee. ...	43
Figure 11.	Yearly Maximum and Minimum Water levels in Lake Okeechobee for the Period from 1932 to 1995.	44
Figure 12.	Soil Subsidence in the Everglades Region of South Florida	49
Figure 13.	Spatial distribution of the major hydric soil types within the EPA in relationship to the key water management gages.	50
Figure 14.	Location, extent and antecedent water conditions for documented historical fires within WCA-3A.	55
Figure 15.	Theoretical position of the saline interface based on the Ghyben-Hertzberg relationship in the Biscayne aquifer	63
Figure 16.	Effects of below minimum water levels on the time required for chloride concentrations to recover in the Biscayne Aquifer	65

List of Tables

Table 1.	Mitigation Actions Available with Governing Board/Executive Director Approval	10
Table 2.	Positive/negative effects of drought on Lake Okeechobee Littoral Zone	45
Table 3.	Minimum flows and levels criteria for organic peat and marl forming soils located within the remaining Everglades.	57
Table 4.	Stages at key water management structures located along Florida's lower East Coast (stages are in feet NGVD)	67
Table 5.	Recommended Minimum Canal Levels and Duration Criteria for the Biscayne Aquifer.	69

Draft Minimum Water Level Criteria - May 12, 1998

List of Abbreviations

ac-ft	acre-feet
cfs	cubic feet per second
C&SF Project	Central and Southern Florida Project for Flood Control and Other Purposes
C&SF Project Restudy	United States Army Corps of Engineers Central and Southern Florida Comprehensive Review Study
DERM	Department of Environmental Resource Management (Dade County)
DNR	Florida Department of Natural Resources
EAA	Everglades Agricultural Area
ENP	Everglades National Park
EPA	Everglades Protection Area (WCA-1, WCA-2, WCA-3, ENP)
FDACS	Florida Dept. of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
FGFWFC	Florida Game and Freshwater Fish Commission
ft	feet
GDM	General Design Memorandum
IAP	Interim Action Plan
LEC	Lower East Coast
LECRWSP	Lower East Coast Regional Water Supply Plan
mg/L.	Milligrams per liter.
MOA	Memorandum of Agreement
msl	mean sea level
NGVD	National Geodetic Vertical Datum
NPS	National Park Service
NSM	Natural Systems Model
SCS	Soil Conservation Service
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
STA	Stormwater Treatment Area
SWIM	Surface Water Improvement and Management
USDA	United States Department of Agriculture
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WCA	Water Conservation Area
WMAs	Water Management Areas
yr	year

GLOSSARY

Acre-foot. Volume of a parallelepiped (box shape) with one side an acre in area, and one foot in depth; 43,560 cubic feet; 1,233.5 cubic meters; 325,872 gallons.

Aquifer. A geologic formation or series of formations which yield water in sufficient quantities to be a valuable source of supply.

Aquifer System. A series of geologic formations which consist of two or more aquifers divided by lower permeability units.

Backpumping. The practice of pumping water that is leaving the area back into a surface water reservoir.

Basin (Ground Water). A hydrologic unit containing one large aquifer or several connecting and interconnecting aquifers.

Basin (Surface Water). A tract of land drained by a surface water body or its tributaries.

Best Management Practices (BMPs). Agricultural management activities designed to achieve an important goal, such as reducing farm runoff, or optimizing water use.

Brackish. Water with a chloride level greater than 250 mg/L and less than 19,000 mg/L.

Dry Season Aquatic Refugia.

Exotic Plant Species. A non-native species which tends to out-compete native species and become quickly established, especially in areas of disturbance or where the normal hydroperiod has been altered.

Ground Water. All water found beneath the surface of the earth in the voids, fractures, and pores or other openings of soil and rock material.

Hydroperiod. The frequency and duration of inundation or saturation of an ecosystem. In the context of characterizing wetlands, the term hydroperiod describes that length of time during the year that the substrate is either saturated or covered with water.

Infiltration. The movement of water through the soil surface into the soil under the forces of gravity and capillarity.

Lake Okeechobee. This lake measures 730 square miles and is the second largest freshwater lake wholly within the United States.

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

Marsh. A frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions.

NGVD. National Geodetic Vertical Datum; reference sea level from which elevations are measured.

Park. Everglades National Park

Permeability. Defines the ability of a rock or sediment to transmit fluid.

Potable Water. Water that is suitable for drinking, cooking, and other domestic purposes. The maximum chloride concentration is 250 mg/L.

Saline Water. Water with a chloride concentration greater than 250 mg/L. The term saline water includes brackish water and seawater.

Saline Water Interface. The hypothetical surface of chloride concentration between fresh water and seawater where the chloride concentration is 250 mg/L at each point on the surface.

GLOSSARY

Saline Water Intrusion. This occurs when dense saline water moves laterally inland from the seacoast, or moves upward, to replace fresher water in an aquifer (upconing).

SCS. The Soil Conservation Service; a federal agency which provides technical assistance for soil and water conservation, natural resource surveys, and community resource protection management.

Semi-Confining Layers. Layers with little or no vertical flow that can store ground water and also transmit it slowly from one aquifer to another. The rate of vertical flow is dependent on the head differential between the semi-confining beds and those above and below them.

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.

Stage. The elevation of the top of a surface water body.

Storm Water. Rainfall that does not percolate into the ground or evaporate.

Subsidence. Lowering of the soil level caused by the shrinkage of organic layers. This shrinkage is due to desiccation, consolidation and biological oxidation.

Surface Water. Water that flows, falls or collects above the surface of the earth.

SWIM Plan. Surface Water Improvement and Management Plan, prepared according to Chapter 373, Florida Statutes.

Transmissivity. This is the rate at which water is 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.

Turbidity. The measure of suspended material in a liquid.

Uplands. Elevated areas which are characterized by nonsaturated soil conditions and support flatwood vegetation.

USACE. United States Army Corps of Engineers.

USEPA. United States Environmental Protection Agency.

USFWS. United States Fish and Wildlife Service.

USGS. United States Geological Survey.

Wastewater. The combination of liquid and waterborne discharges from residences, commercial buildings, industrial plants and institutions together with any ground water, surface runoff or leachate that may be present.

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

Water Supply Plans. These plans are regional water resource and demand analyses. They are District generated, and provide a detailed evaluation of available water supply and projected demands through the year 2010.

Wetlands. Areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.

-DRAFT-
Minimum Water Level Criteria

I. INTRODUCTION

This report documents the methods and technical criteria used by staff of the South Florida Water Management District (SFWMD or District) to develop proposed minimum flows and levels for the Biscayne aquifer, Lake Okeechobee, and the remaining Everglades (which includes the Water Conservation Areas (WCAs), the Holey Land/Rotenberger Wildlife Management Areas and Everglades National Park). The District is also proceeding with efforts to develop minimum flows and levels for associated areas such as the Caloosahatchee River Estuary by the year 2000, the Loxahatchee and St. Lucie estuaries by the year 2001, and Biscayne Bay by the year 2004 (FDEP, 1997).

The District Water Management Plan (DWMP) for South Florida (SFWMD, 1995b) includes a schedule for establishing minimum flows and minimum water levels for priority water bodies within the District. Ch 373 requires the water management Districts to annually review this list and schedule and make any necessary revisions. The SFWMD submitted a revised priority list and schedule to Florida Department of Environmental Protection in November, 1997. This schedule indicates that minimum water levels and flows were to be established by 1999 for four priority areas -- Lake Okeechobee, the Water Conservation Areas, Everglades National Park (except for Florida Bay) and the Biscayne Aquifer.

As a first formal step to meet the deadlines for Lake Okeechobee, the Everglades and the Biscayne Aquifer, this report includes:

- a) A conceptual framework for determining minimum flows and levels based on the best scientific information and ecological criteria available -- an approach that may be applied to other surface and ground waters within the District;
- b) Technical criteria for developing minimum flows and levels for Lake Okeechobee, the Water Conservation Areas, Holey Land/Rotenberger Wildlife Management Areas, Everglades National Park, and the Biscayne aquifer based on the conceptual approach.

A. LEGAL BACKGROUND

The Florida Legislature has mandated that all water management districts establish minimum flows and levels for surface waters and aquifers within their jurisdiction. *Section 373.042(1)* defines the minimum flow as "...the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area...." Likewise, *Section 373.042 (1), F.S.*, defines the minimum level as the "...level of ground water in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area..." The SFWMD is directed to use the best available information in establishing a minimum flow or minimum level (*Section 373.042, F.S.*). Each water management district must also consider, and at its discretion may provide for, the protection of nonconsumptive uses in the establishment of minimum flows and levels.

Passage of the minimum flows and levels laws in 1997 (CS/HB 715, 1249, 321 & 1339), codified in Sections 373.042 and 373.0421, F.S., added several additional requirements to the minimum flows and levels statute. These include:

-DRAFT-
Minimum Water Level Criteria

- When establishing a minimum flow or level, the District shall consider changes and structural alterations to watersheds, surface waters and aquifers and the effect such constraints or alterations have had on the hydrology of the area. Such considerations shall not allow significant harm caused by withdrawals.
- The Legislature also recognized that certain water bodies no longer serve their historic hydrologic functions, and that recovery of these areas may not be economically or technically feasible, and could cause adverse environmental or hydrologic impacts. Accordingly, water management districts may determine that setting a minimum flow or level for such a water body based on its historical condition is not appropriate. This exclusion does not apply to the Everglades or Lake Okeechobee.
- Exclusions, designating resources for which minimum flows or levels can not be adopted, are provided for surface water bodies less than 25 acres in size, and for constructed water bodies, unless such areas have significant value, or are important to the water resources of the area. These exclusions **do not** apply to the Everglades or Lake Okeechobee.
- If the existing flow or water level is expected to fall below the established minimum flow and level criteria, the District is required to develop and implement a recovery or prevention strategy for those water bodies that are expected to exceed the proposed criteria.

Establishing *minimum* levels alone will not be sufficient to maintain a sustainable resource or protect it from harm. For both Lake Okeechobee and the Everglades, floods or extended periods of high water also impact the resource. Setting minimum levels is viewed as a starting point from which to define the necessary hydrologic regime for restoration of the entire Kissimmee-Lake Okeechobee-Everglades ecosystem. Achieving the required water levels throughout this system is an overall, long-term restoration goal. *Maximum* levels for Lake Okeechobee and the Water Conservation Areas (WCAs) are controlled by regulation schedules for these areas, but the overall ability of these schedules to protect the resource is uncertain, especially during above normal rainfall years due to the limited water storage capacity of the regional system. As a result, new or revised maximum water level criteria are being considered as part of the Lower East Coast Regional Water Supply Plan process for certain areas, such as WCA-3A, 3B and 2A, to protect existing tree islands. The maximum water level for Lake Okeechobee, as determined by the regulation schedule, is currently being reviewed by the United States Army Corps of Engineers (USACE), the District and other agencies.

B. PROCESS FOR ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS (MFLs).

1. Process Steps and Activities.

The following process for establishment of minimum levels for Lake Okeechobee, Water Conservation Areas, Holey Land/Rotenberger, Wildlife Management Areas Everglades National Park, and the Biscayne aquifer, is defined in the Interim Plan for the Lower East Coast Regional Water Supply (SFWMD, 1998). This process includes:

-DRAFT-
Minimum Water Level Criteria

- a. Revise the current draft (1997) of the MFL Technical Criteria document by incorporating comments received from the public and various agencies (ongoing). Complete revisions to the draft by June, 1998.
- b. Seek Governing Board approval of the proposed draft, along with Governing Board consideration of the policy implications of the proposed minimum flows and levels. This will probably be a two or three-month process including two Governing Board meetings.
- c. Conduct independent scientific peer review of the revised Minimum Flows and Levels technical document and incorporate the revisions suggested by the panel as deemed appropriate. Complete this process by August, 1998.
- d. Continue the development of a MFL Recovery and Prevention Strategy for the Biscayne aquifer, Everglades National Park, the Water Conservation Areas, Holey Land/Rotenberger Wildlife Management Areas, and Lake Okeechobee based on the peer reviewed MFL technical document. Complete the draft recovery strategy during 1999..
- e. As part of the development of the recovery strategy, conduct appropriate technical analyses to determine the water supply implications of the proposed minimum flows and levels criteria on urban and agricultural users. These results will be integrated into the final LEC Regional Water Supply Plan analysis with appropriate implementation measures developed consistent with Section 373.0421 Florida Statutes. This plan is due to be completed in 2000.
- f. Following completion of the scientific peer review process (August 1998), the District will initiate Rule Development, after Governing Board consideration of the peer review results and appropriate revisions to the document are made. Rule development will be completed by December, 1999.
- g. Field monitoring and laboratory research programs have been initiated to evaluate the effects of implementing the proposed MFL criteria proposed as part of this plan. This effort includes both short-term and long-term projects that will evaluate the effects of the proposed criteria at scales ranging from laboratory studies to field scale monitoring projects.

2. Scientific Peer Review.

After Governing Board authorization, the District will coordinate an independent scientific peer review of the draft minimum flows and levels document under Section 373.042, F.S. That section requires '*independent scientific peer review*' (s.373.019, (9)) of the technical development of minimum flows and levels, stating:

"Independent scientific peer review" means the review of scientific data, theories and methodologies by a panel of independent, recognized experts in the fields of hydrology, hydrogeology, limnology and other scientific disciplines relevant to the matters being reviewed under s.373.042.

The selected peer review panel is required to submit the final report within 120 days after their selection, unless waived. In every review of MFLs, the panel will act as a concurrent, interactive group of experts and will participate in at least one open meeting in an appropriate location within the District during the review process.

-DRAFT-
Minimum Water Level Criteria

Once final data, methodologies and models, including all scientific and technical assumptions employed in each model upon which a minimum flows or level is based have undergone peer review, no additional peer review under the statute will be required. The final report is to be given significant weight when establishing MFLs.

C. MFL RECOVERY AND PREVENTION STRATEGY.

The 1997 Water Bill requires that once the Minimum Flows and Levels criteria have been established, the Districts must develop a recovery and prevention strategy for those water bodies that are expected to exceed the proposed criteria. It is probable that the proposed Minimum Flows and Levels criteria cannot be achieved immediately because of the lack of adequate regional storage in the system and ineffective water distribution infrastructure. These storage and infrastructure shortfalls will be resolved through construction of facilities increase the region's storage capacity and improve the existing delivery system. Planning and regulatory efforts will therefore include a programmed recovery process that will be implemented over time to improve water supply and distribution to protect critical resources.

It is anticipated that such changes will occur gradually over a period of years due to the large funding and construction requirements of such projects. As a result, District staff recommends a phased approach to achieving minimum flows and levels within each of the priority water bodies discussed below. Phased implementation will also provide opportunities for utilities and drainage facilities, whose present operations may impact water levels in Lake Okeechobee the Everglades Protection Area, to shift their usage to alternative sources. This has a two-fold advantage, since it allows more water to remain in the Everglades and Lake Okeechobee and also allows utilities to obtain a greater level of certainty concerning availability of the water source. Phased implementation may thus reduce the economic impact on users and still provide for long term protection of resources.

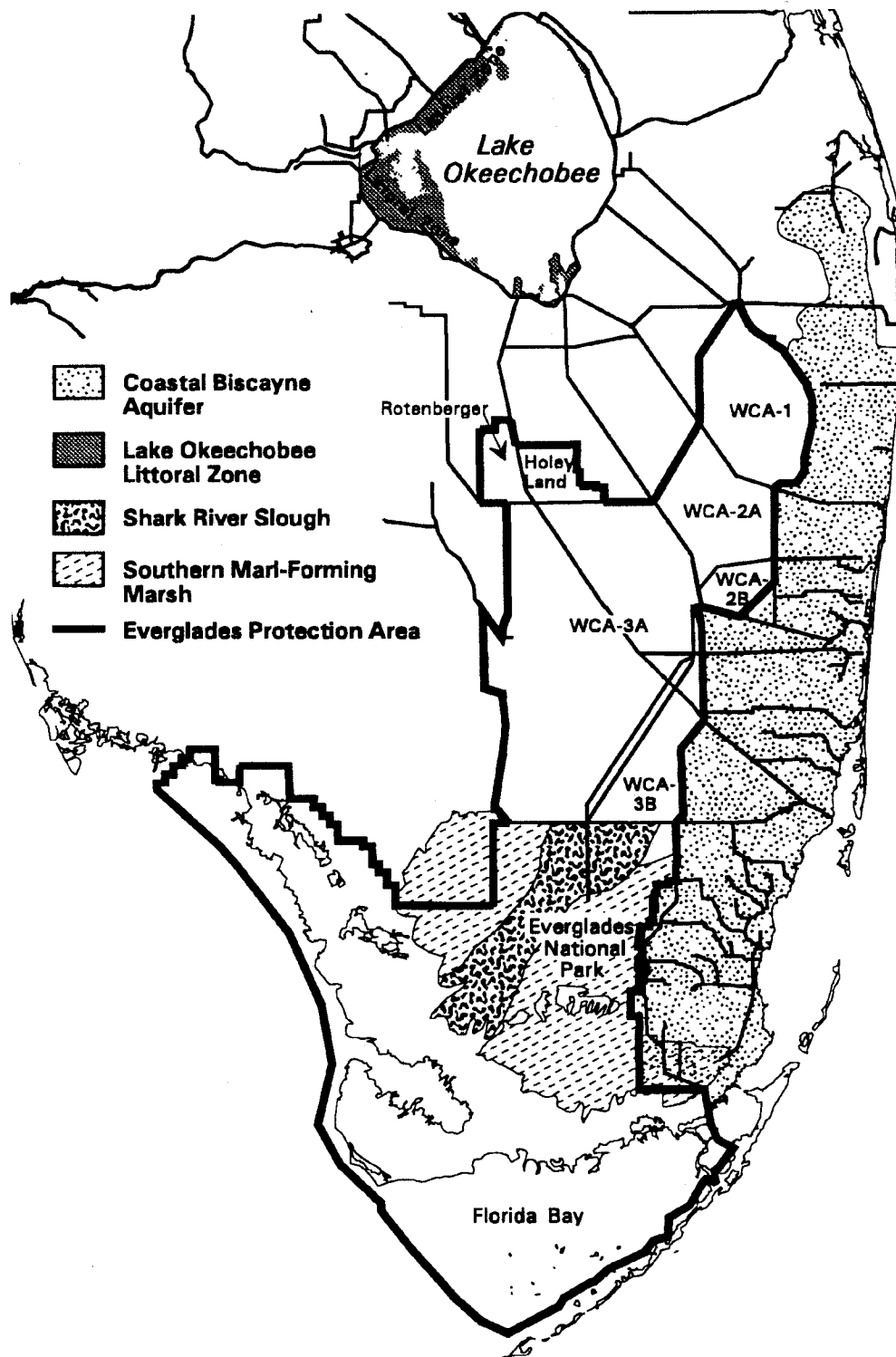
D. DESCRIPTION OF PRIORITY WATER BODIES

1. Lake Okeechobee.

Major Features.

Lake Okeechobee is a large, shallow, eutrophic lake located in south central Florida (**Figure 1**). The lake is often referred to as the "liquid heart" of South Florida's interconnected Kissimmee River-Lake Okeechobee-Everglades ecosystem. With a surface area of more than 730 sq. mi., Lake Okeechobee represents the third largest lake in the United States. The lake is a multipurpose reservoir developed as part of the Central and Southern Florida Project (C&SF Project) for the purposes of flood control; providing water for surrounding lakeside communities; supplemental water supply for more than 3.5 million persons living along Florida's Lower East Coast; supplemental irrigation water for agriculture; protection of the Biscayne aquifer against saltwater intrusion; enhancement of fish and wildlife resources; navigation and recreation benefits; and provides a source of water for Everglades National Park. The District and the USACE have the primary responsibility for management of water levels in the lake, the Florida Department of Environmental Protection (FDEP) and District are the primary state agencies responsible for water quality protection, while the Florida Game and Freshwater Fish Commission (FGFWFC) manages fish and wildlife resources.

**-DRAFT-
Minimum Water Level Criteria**



Source: SFWMD

Figure 1. Priority Areas for Establishing Minimum Flows and Levels in South Florida.

-DRAFT-
Minimum Water Level Criteria

Lake Okeechobee was formed approximately 6,000 thousand years ago (Hutchinson, 1957). Historic maximum water levels were estimated to range from 19.7 - 21.3 feet (Brooks, 1974). In its original condition, the lake was considerably larger than it is today and consisted of an extensive littoral marsh system extending to the north, west and south of the lake. Construction of the levee system (Herbert Hoover Dike) around the lake and the lowering of lake levels from a maximum of 20 ft. to 17 ft. NGVD effectively isolated thousands of acres of marsh, creating a new littoral zone/marsh community in areas where it had not previously existed. This wetland area now occupies more than 20% (98,000 acres) of the total surface area of the lake and provides habitat for a wide variety of plant and animal communities, including a number of rare, threatened, or endangered species such as the snail kite, wood stork, West Indian manatee and the Okeechobee gourd (SFWMD, 1993a). The littoral zone provides an important nursery ground and habitat for fish and other aquatic organisms. Migratory birds and waterfowl also utilize the littoral zone and open water areas of the lake as a resting area along the Atlantic flyway (Aumen, 1995).

The lake is also important to navigation and represents a recreational resource of regional importance. The lake is part of the Okeechobee Waterway connecting the east and west coasts of Florida. The lake also supports a nationally renowned sport fishery for largemouth bass, black crappie, bluegill, redear sunfish, and catfish. Recreational and commercial fisheries combined have an estimated value of more than \$28 million dollars per year (Bell, 1987). The lake's littoral zone also supports significant wading bird populations and is an important waterfowl hunting area.

Water Resource Issues.

The major water resource issues associated with management of Lake Okeechobee include the following:

- **Water Supply:** Much of South Florida depends on Lake Okeechobee as its primary water supply during low rainfall periods. Future population growth, land use changes and competing water supply needs will have significant effect on future water levels and water storage in Lake Okeechobee. Model simulations for the year 2010 show the increased likelihood of severe water shortages and water supply cutbacks within the Lake Okeechobee and Lower East Coast Service Areas (SFWMD, 1998). This reduced water supply has the potential to increase the problem of saltwater intrusion along Florida's Lower East Coast during dry periods.
- **Flood Protection:** During 1997 and 1998, a number of extreme rainfall events have increased water depths to levels which exceed the current regulation schedule and threaten the structural integrity of the levee system that surrounds the lake. To maintain an acceptable level of flood protection for communities that surround the lake, water levels during the hurricane season must be maintained at safe levels (<16.5 ft. NGVD) that will not threaten the levee system.
- **Water Quality:** Declining water quality and increased frequency of algal blooms have occurred in the lake as a result of increased nutrient loading that result from non-point sources of pollution originating from agricultural lands located north of the lake (Aumen 1995; SFWMD 1997). This issue has been addressed through adoption and implementation of the Lake Okeechobee SWIM Plan (SFWMD 1989, 1992, 1997) to reduce nutrient loading to the lake.

-DRAFT-
Minimum Water Level Criteria

- Impacts to Estuaries: During periods of high rainfall, large regulatory releases of freshwater are made to the St. Lucie and Caloosahatchee estuaries. These discharges cause wide fluctuations in salinity within the inner estuary and impact estuarine biota (Haunert 1988; Chamberlain *et al.* 1994)
- Littoral Zone: Long-term flooding of the littoral zone (>15.0 ft. NGVD) reduces the diversity and abundance of beneficial wetland vegetation (e.g., bulrush, eel-grass, pondweed, spike rush and willow) while increasing the abundance of cattails, torpedo grass and hydrilla which provide poor habitat for fish and wildlife (Zaffke, 1983; Milleson 1987; LOLZTG 1988; Richardson 1994). A primary issue related to defining a minimum water level for the lake is the determination of an appropriate water level regime (hydroperiod) that will maintain the ecological integrity of the littoral zone.
- Exotics: Expansion of undesirable aquatic weeds and exotic plants (torpedo grass, melaleuca, hydrilla, water lettuce, and water hyacinths) have become a threat to the lake ecosystem because of their rapid expansion into areas once occupied by native species. These infestations hinder recreational use of the lake and require expensive chemical treatment (Aumen 1995).

Water Management Features.

Lake Okeechobee represents South Florida's most effective water storage area. Water levels within Lake Okeechobee are managed using a rule curve or regulation schedule, while water allocation to downstream users is managed using a combination of the District's Water Shortage Plan (SFWMD, 1989), and Supply-side Management Plan for Lake Okeechobee (Hall, 1991) as discussed below:

Lake Regulation Schedule. Water levels within the lake are managed according to a regulation schedule developed by the SFWMD and USACE (**Figure 2**). The schedule is designed to maintain a low level of 15.6 ft. NGVD during the wet season to provide storage capacity for excessive rainfall amounts and prevent flooding in surrounding areas. Water levels are allowed to reach peak stages of 16.5 ft. at the end of the wet season to store water in the lake for the upcoming dry season. The schedule determines the timing and quantity of water that needs to be released from the lake when lake stages exceed certain flood control zones, which vary according to season (**Figure 2**). The USACE operates the primary structures and navigation locks around the lake and is responsible for maintenance of this schedule. The SFWMD operates and maintains the secondary water control structures and pump stations. Several schedules have been implemented over the past 50 years in response to regional water storage and flood control needs. The lake has been regulated from a minimum of 12.5 to 14.5 ft msl in the late 1940's, up to 15.5 to 17.5 ft. NGVD in effect from 1979 to 1990. In 1991, the District proposed a number of modifications to the schedule known as "Run 25" that allows for multiple water release zones to better control downstream discharges to the St. Lucie and Caloosahatchee estuaries. Included within the schedule are a series of pulse release zones (Levels I, II, and III) where smaller releases of freshwater are made to downstream estuaries (**Figure 2**) in anticipation of the lake reaching levels that would require large regulatory releases that damage downstream estuaries. More detailed descriptions of the history and operation of Lake Okeechobee's regulation schedule may be found in the following references, Trimble and Marban (1988); the Lake Okeechobee SWIM plan Update (SFWMD, 1997); and Neidrauer *et al.* (1997).

-DRAFT-
Minimum Water Level Criteria

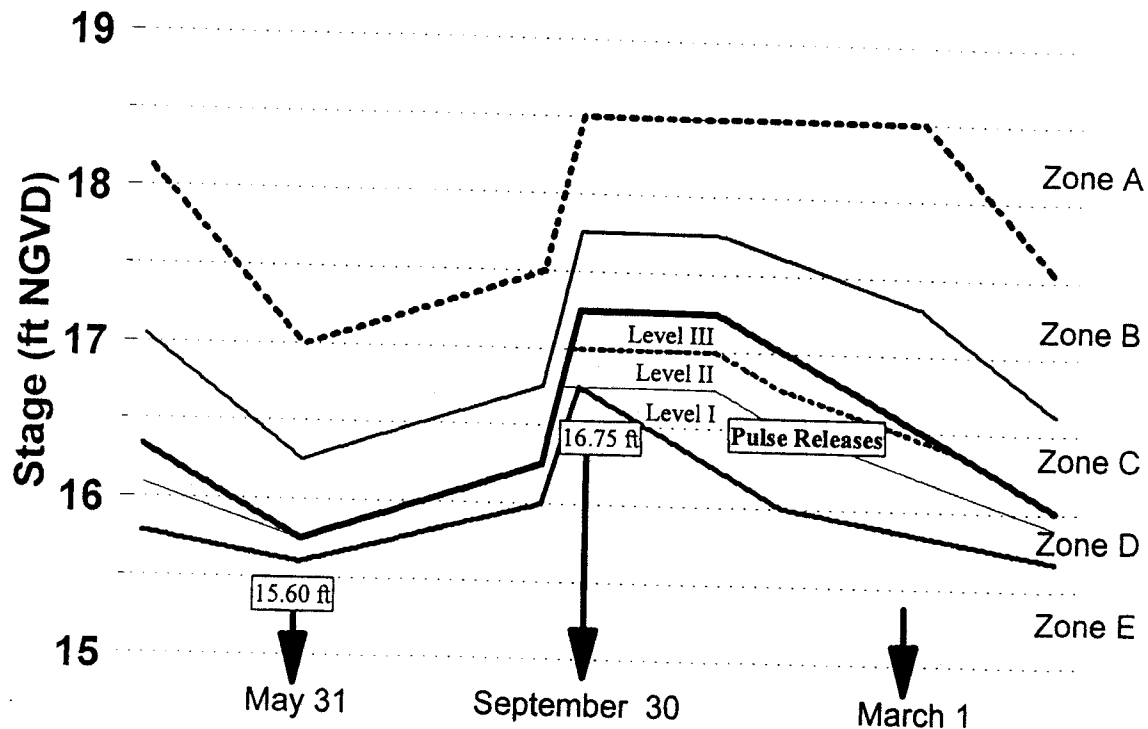


Figure 2. Lake Okeechobee Regulation Schedule "Run 25"

Drought Management. During years of normal rainfall, the lake's current regulation schedule allows for an ample supply of water to be stored in the lake during the wet season for later use in the dry season. Lake Okeechobee receives on average, approximately 43 inches of rainfall each year (period of record 1965-1995). This rainfall amount however, varies widely from year to year and from season to season. This variability tends to produce erratic and unpredictable rainfall conditions which can result in drought. In addition to this climatic variation, South Florida's rapid growth produces an ever-increasing demand on the region's available water supply during low rainfall periods. Historical records show that when lake levels fall below 11.0 ft. NGVD, water shortage restrictions are imposed by the District along Florida's lower east coast. Once below 11.0 ft., lake levels decline rapidly affecting the District's ability to deliver water to downstream users as well as affecting the ecology of the lake. More importantly, as water levels drop below 10.0 ft. NGVD, structural limitations of the lake's outlet structures make it increasingly difficult to withdraw water from the lake to send downstream to protect lower east coast wellfields against saltwater intrusion.

To avoid extreme drawdowns that impact both the ecology of the lake and South Florida's reserve water supply, the District developed a water supply management plan for Lake Okeechobee (Water Shortage Manual, SFWMD, 1987; Supply-side Management Plan for Lake Okeechobee, Hall, 1991). The plan was developed in 1982 and serves as the basis for making water management decisions during periods of low rainfall. The primary objective of the plan is to ensure that adequate water is held in reserve within the lake for later, high demand periods, but is yet responsive to the short-term needs of users who depend on the lake as their primary water source.

The basis of the plan is an allocation strategy which parcels out lake water based on weekly estimates of water use and demand for various user groups for the

-DRAFT-
Minimum Water Level Criteria

remainder of the dry season. Water availability is based on three factors, anticipated rainfall, lake evaporation, and downstream water needs for the balance of the dry season, in relation to the amount of water in storage. Each factor used in the computation of weekly water allocations is based on normal values expected to occur over the balance of the dry season. A critical water level target was established in the lake as 11.0 ft. NGVD. The 11.0 ft criterion was selected based on the need to provide this reserve supply of water within the lake to prevent saltwater intrusion of the coastal aquifer as well as protection of lake's littoral zone. Water allotments are computed so that water levels will not fall below the target level stage by the end of the dry season (May 31st). The volume of water reserved in the lake between elevation 11.0 ft. and 10.0 ft. NGVD is approximately 327,000 ac-ft. The plan is based on six critical lake water level conditions that require various actions to be taken according to the severity of the conditions exhibited (see below and **Figure 7**, Section III of this report) These include:

Condition 1: Watch

- Definition:** There is roughly enough water supply in the lake to meet the water demands of a 1 in 5 year drought.
- Action:** Publicize conditions at Governing Board meetings and in response to press inquiries.

Condition 2: Warning

- Definition:** Enough water is stored in the lake to meet water use demands of a 1 in 3 year drought.
- Action:**
- (a) Begin mobilization of the District's Supply-side Management task Force; make personnel assignments for appropriate departments.
 - (b) Notify, and obtain approval from, the USACE to enforce Lake Okeechobee water use restrictions should conditions worsen.
 - (c) Contact key individual water users and organizations.

Condition 3: Implement Phases 1, 2, 3 and 4 water use restriction for the lower east coast as water levels fall within water supply management Zones A, B, C, and D of the Lake Okeechobee Water Shortage Management Plan (**Figure 7**).

- Definition:** Water levels within this range indicate, with normal rainfall and average water demand for the remainder of the dry season, the lake will fall below the critical 11.0 ft. NGVD by May 31st.
- Action:** Implement the Lake Okeechobee water allocation plan as follows:
- (a) All water releases from the lake will be based on the assumptions of average climatic conditions and average water use conditions with a May 31st target lake stage of at least 11.0 ft. maintained.
 - (b) Mitigation actions approved by the SFWMD's Governing Board may be permitted as outlined in **Table 1** below.
 - (c) The Executive Director of SFWMD may conduct public meetings of major Lake Okeechobee users (if appropriate).

The plan is based on a "live within our means" concept and requires water managers to prudently budget, save and distribute water according to needs during a water shortage period. The plan provides (a) a balanced water allocation strategy for all users that attempts to avoid severe drawdowns of the lake, (b) a method for holding water in reserve for anticipated high-demand periods, and (c) identifies a

-DRAFT-
Minimum Water Level Criteria

defined minimum lake level that will protect the ecology of the lake (i.e., the littoral zone) and prevent saltwater intrusion of LEC wellfields.

Table 1. Mitigation Actions Available with Governing Board/Executive Director Approval

MONTH	ZONE B	ZONE C
Oct.	*Shift 1/3 February Allotment	Shift 2/3 February Allotment
Nov.	Shift 1/3 March Allotment	Shift 2/3 March Allotment
Dec.	Shift 1/3 April Allotment	Shift 2/3 April Allotment
Jan	Shift 1/3 May Allotment	Shift 2/3 May Allotment
Feb.	** Lower Target to 10.75 ft.	Lower Target to 10.5 ft
March	Lower Target to 10.5 ft.	Lower Target to 10.25 ft.
April	Lower Target to 10.25 ft.	Lower Target to 10.0 ft.
May	Lower Target to 10.0 ft.	Lower Target to 9.75 ft.

* "Shift" means to add part of a future month's water allotment to the current month's amount.

** Lowering the target increases monthly allotments but may result in very low lake levels going into the wet season.

Operational decisions on water releases from Lake Okeechobee to downstream users are made jointly by the USACE and SFWMD Governing Board after full consideration of local, regional, and environmental water resource issues have been reviewed. Under emergency drought conditions, the Governing Board has the operational flexibility to go below the target minimum level of 11.0 ft. NGVD at the end of dry season to make critical water supply deliveries to the lower east coast to protect wellfields against saltwater intrusion (Table 1).

The plan also allows users to "borrow water" from their future water supply, which is held in reserve by supply-side management, for use in the early dry season. This borrowing provision places the decision of risk on the user in the amount of water that could be borrowed because this value is subtracted from their later month's water allocation. Computational procedures for determining the amount of water available in storage which could be allocated to users to meet dry season demands can be found in detail in Hall (1991). The Supply-Side Management Plan has been adopted by the SFWMD Governing Board and has been in operation for six years. It is the consensus of the various agencies that manage the lake and its downstream water resources that the Supply-Side Management Plan is the best operational plan available for managing South Florida's limited water supply

2. The Everglades.

Major Features.

The Everglades is an internationally recognized ecosystem that covers approximately two million acres in South Florida and represents the largest subtropical wetland in the United States. This area has been described as a vast sawgrass marsh, dotted with tree islands and interspersed with wet prairies and aquatic sloughs that historically covered most of southeastern Florida (Davis, 1943a). Today's remaining Everglades is comprised of the Water Conservation Areas (WCA-

-DRAFT-
Minimum Water Level Criteria

2A, WCA-2B, WCA-3A, WCA-3B, and WCA-1), the Holey Land and Rotenberger Wildlife Management Areas, and Everglades National Park (ENP), which also includes Florida Bay (**Figure 1**). Water Conservation Areas 2 and 3 together are also designated as the Everglades (Francis S. Taylor) Wildlife Management Area. Water Conservation Area 1 is also known as the Arthur R. Marshall Loxahatchee National Wildlife Refuge. Everglades National Park and the Water Conservation Areas (WCAs) were designated as Outstanding Florida Waters in 1978 and are the surviving remnants of the historical Everglades which extended over an area approximately 40 miles wide by 100 miles long, from the south shore of Lake Okeechobee to the mangrove estuaries of Florida Bay. This remaining area provides significant ecological, water storage, flood control, and recreational benefits to the region as well as important habitat for wildlife of national significance.

Water Resource Issues.

A number of structural changes or alterations that have occurred to the regional ecosystem were considered during the development of minimum flows and levels criteria for the Everglades Protection Area. Construction of the Central and Southern Florida Project and large-scale urban and agricultural development have isolated large segments of original Everglades from the natural system by canals and levees. More than half of the original system has been lost to drainage and development (Davis and Ogden, 1994). Today, these developed areas support a variety of land uses, ranging from intensively managed agriculture in the north (Everglades Agricultural Area) to rapidly spreading urban areas located east of the WCAs. The major water management issues currently confront the EPA include:

- Loss of Dynamic Storage and Spatial Extent. Loss of over 50 percent of the original ecosystem has reduced the water storage capacity of the ecosystem considerably. Loss of the ability to store large volumes of water that slowly moved as sheet flow across the Everglades landscape increases the system's susceptibility to the effects of flood and drought. Reduction of the original Everglades ecosystem by half as a result of land development activities has placed a fundamental limitation on its capacity to support populations of wading birds, alligators, and panthers that once used the area in much greater numbers (Davis and Ogden, 1994, Science Subgroup 1994, USACE, 1994).
- Fragmentation of the Everglades. The historical system has been subdivided by construction of canals, levees, roads and other facilities and has resulted in the loss of connections between the central Everglades and adjacent transitional wetlands. Everglades wildlife communities and sustainability of the ecosystem may be impaired by this separation and isolation. Construction of canals and levees and impoundment of the WCAs have caused overdrainage of some areas and excessive flooding in other areas (USACE, 1994).
- Changes in Timing, Distribution and Quantity of Water. Altered discharges into, within and between freshwater wetlands and estuaries have led to destruction, loss or degradation of native Everglades plant communities and associated wildlife habitat (SFWMD 1992; Davis *et al.* 1994; Davis and Ogden 1994).
- Water Quality. High concentrations of phosphorus in waters that are discharged into the Everglades from the agricultural and urban areas are causing adverse changes in plant communities and wildlife habitat within the

-DRAFT-
Minimum Water Level Criteria

WCAs and potentially threaten the ecological integrity of ENP (SFWMD 1992; Everglades Forever Act, Chapter 373.4592 F.S. 1994)

- Invasion of Native Plant Communities by Exotic Species. Species such as melaleuca (Bodle *et al.* 1994), Australian pine and Brazilian pepper have displaced native plants and degraded or destroyed wildlife habitat.
- Impacts to Estuaries. Adequate quantity, timing and distribution of water must be discharged from the freshwater areas of ENP and the WCAs downstream to the Florida Bay and Biscayne Bay to maintain the biological integrity of these estuarine ecosystems (Boesch *et al.* 1993; Bancroft, 1993; Fenemma *et al.* 1994).

The Water Conservation Areas (WCAs).

The three Water Conservation Areas are an integral component of the Everglades and an important source of water supply for South Florida. The WCAs, located south of Lake Okeechobee and east of the heavily urbanized Lower East Coast, comprise an area of about 1,350 square miles (**Figure 1**). Although originally part of the larger Everglades ecosystem, these remaining wetlands today serve multiple purposes: (a) detention areas for excess water discharged from Lake Okeechobee and flood control discharges from the Everglades Agricultural Area and portions of the lower east coast; (b) sources of water supply for lower east coast agricultural lands and urban areas by recharging the Biscayne aquifer and retarding salt water intrusion in coastal wellfields; (c) sources of water supply for Everglades National Park; (d) important habitats for Everglades wildlife; and (e) public recreational uses.

Water Conservation Area 1.

Physical Characteristics: Water Conservation Area 1 (WCA-1) is designated as the Arthur R. Marshal Loxahatchee National Wildlife Refuge and is managed by the U.S. Fish and Wildlife Service (USFWS). WCA-1 covers an area of 221 sq. mi. within Palm Beach County. The West Palm Beach Canal discharges agricultural drainage water into the north end of WCA-1 via pump station S-5A and the Hillsboro canal and pump station S-6 discharges water into the southwestern portion. The area is enclosed by 58 mi. of levees and provides storage for excess rainfall and runoff from the Everglades Agricultural Area (EAA). Ground level elevations range from 16 ft. NGVD at the north end to 12 ft. at the south end of the Refuge. The current minimum water level maintained within the perimeter canal is 14 ft. NGVD. Below this level, water releases are not permitted unless water is supplied from another source. WCA-1 is an important source of water supply for urban areas located in Palm Beach and northern Broward counties.

Management Issues: Historical data suggests that WCA-1 was originally a much wetter area and was part of the Hillsboro Lakes region of the Everglades (Davis 1943a; Parker *et al.* 1955). Canal construction and drainage activities have eliminated overland sheet flow that once sustained prolonged hydroperiods within this region. Soils data (Gleason and Spackman, 1974), long-term vegetation studies (Alexander and Crook, 1984) and hydrologic models developed for the Everglades (Fenemma *et al.* 1994) also suggest that WCA-1 was generally much wetter prior to the construction of drainage canals. Based on this information, the USFWS proposed a change in the WCA-1 regulation schedule to provide deeper water, with longer hydroperiods, in an effort to restore the natural ecosystem functions of the original Hillsboro Lakes marsh system. The newly-implemented schedule calls for

-DRAFT-
Minimum Water Level Criteria

maintaining a minimum water level of 14 ft. NGVD and allows a maximum stage of 17.5 ft. NGVD. This higher schedule will (a) allow higher water levels during wet years in the northern portion of the refuge, (b) increase hydroperiod within the interior marsh to reduce the frequency of annual drying of the marsh, (c) improve the timing of the winter drawdown to benefit nesting wading birds, (d) restore snail kite habitat, and (e) allow for more storage of water within the system during wet and normal rainfall years.

Water Conservation Areas 2A and 2B.

Physical Characteristics: Water Conservation Areas 2 and 3 together are designated as the Everglades (Francis S. Taylor) Wildlife Management Area. Water Conservation Area 2A is an extensive sawgrass wetland that encompasses an area of 210 sq. mi. and is the smallest of the three Water Conservation Areas located within southern Palm Beach and northern Broward counties (**Figure 1**). Water levels in WCA-2A are controlled by a system of levees and water control structures which encircle the marsh. WCA-2A provides a variety of functions including the following: (a) aquifer recharge for and protection against salt water intrusion for east coast well fields; (b) flood protection for agricultural and east coast urban areas; (c) preservation of Everglades wildlife including threatened or endangered species; and (d) recreational opportunities (hunting, fishing, boating and wildlife observation) for South Florida residents. Management of water levels is the responsibility of the District in accordance with regulation schedules set by the USACE while the Florida Game and Freshwater Fish Commission is responsible for wildlife management. Water regulation schedules range from 13 ft. NGVD at the end of the wet season (September 15) to 11 ft. NGVD from February 1 through June 15 (dry season). The current minimum water level maintained within the L-35B and L-38 borrow canals is 10.5 ft. NGVD below which water releases are not permitted unless water is supplied from another source.

More than half of the inflow water entering WCA-2A originates from the EAA (SFWMD, 1992). Canal inflow waters are highly mineralized and contain high concentrations of nitrogen and phosphorus resulting from the oxidation of organic peat soils within the EAA (SFWMD, 1992). The canals also convey water from Lake Okeechobee, which has been enriched by agricultural activities north of the lake. In 1961, a levee (L-35B) was constructed across the southern portion of WCA-2 dividing the area into two smaller units, WCA-2A (173 sq. mi.) and WCA-2B (37 sq. mi.), in an effort to reduce water seepage losses to the south and to improve the water storage capabilities of WCA-2A.

Management Issues: This area has been severely affected by stabilized hydroperiods and high regulation schedules that were maintained during the late 1960's and 1970's. Wetlands in the central and southern portions of WCA-2A were flooded for extended periods, resulting in loss of tree islands and conversion of wet prairies to aquatic sloughs (Dineen, 1972; Worth, 1988). Changes have been made to the WCA-2A regulation schedule to mitigate adverse impacts of prior regulation schedules. Many of the ecological losses that occurred in the 1960s and 1970s, however, may take many decades to repair with improved management of water levels. In the northeastern portion of WCA-2A, long-term discharges of elevated nutrient concentrations through the S-10 structures, in combination with altered hydroperiod and fire, have caused significant changes in existing vegetation communities (Swift and Nicholas, 1987; Davis *et al.*, 1994; Rutchev and Vilchek, 1994; Jensen *et al.* 1995). This area is currently a major focus of Everglades restoration efforts.

-DRAFT- Minimum Water Level Criteria

Water Conservation Areas 3A and 3B.

Physical Characteristics: The largest of the water conservation areas, WCA-3 covers an area of 915 sq. mi., and is located in western Broward and Dade counties (Figure 1). The area is predominately a vast sawgrass marsh dotted with tree islands, wet prairies and aquatic sloughs. A cypress forest fringes its western border along the L-28 Gap and extends south to Tamiami Trail.

In 1962, WCA-3 was divided into WCA-3A and WCA-3B (786 and 128 sq. mi., respectively) by construction of two interior levees (L-67A and L-67C) so that water losses due to levee seepage could be reduced. WCA-3A is the only water conservation area that is not entirely enclosed by levees. The L-28 Gap allows overland flow to enter WCA-3A from the Big Cypress National Preserve and other western basins. WCA-3A is bisected by several major canals such as the Miami Canal which drains the EAA. Water also enters the area via the S-9 pump station, which drains urban areas located within western Broward County, and a combination of agricultural and WCA-2A sheet flow from the S-11 structures. Management of water levels within WCA-3A and WCA-3B is the responsibility of the District in accordance with regulation schedules set by the USACE. Wildlife management is delegated to the Florida Game and Freshwater Fish Commission under lease from the SFWMD.

Water levels in WCA-3A are regulated from 9.5 to 10.5 ft. by a regulation schedule, using the average stage of gages 3A-3, 3A-4 and 3A-28. During droughts, a minimum elevation in the borrow canal of 7.5 ft. NGVD is observed. Below this elevation, no further releases are permitted from WCA-3A unless a supply of water from another storage area is transferred to WCA-3A (USACE, 1992).

WCA-3A serves a variety of functions including: (a) aquifer recharge and protection against salt water intrusion for east coast urban areas; (b) flood protection for agricultural and east coast urban areas; (c) habitat for preservation of Everglades wildlife including threatened or endangered species; (d) recreational opportunities (hunting, fishing, boating and wildlife observation) for South Florida residents; and (e) a source of high quality inflow water for Everglades National Park.

Management Issues: The initial WCA-3A operating schedule and configuration of water management structures has caused the overdrainage of northern WCA-3A resulting in loss of organic soils, tree islands and wet prairies due to soil subsidence and peat fires (Zaffke, 1983; Schortemeyer, 1980). Satellite maps show that much of northern WCA-3A is transitioning from wetlands to brush vegetation (primarily wax myrtle and willow) and large areas of eastern WCA-3A are being invaded by cattail.

Construction of Alligator Alley and the associated borrow canal have restricted sheet flow of water to the south. The location and design of the Miami Canal have contributed to the overdrainage of the northern end of WCA-3A. Water discharged through the S-8 pump station moves south in the canal much more rapidly than historic sheet flow. Additional environmental enhancement structures have been added, such as S-339 and S-340 in the Miami Canal, to induce more sheet flow through the marsh, but have not solved the problem. Overall, sheet flow within WCA-3A must be restored, especially in critically impacted northern areas, to protect the natural resources. Water levels in the northern portion should be raised during dry periods to reduce the incidence of severe muck fires. In contrast, construction of the L-29 levee across the southern end of WCA-3 in 1962 interrupted the southerly flow of water to Everglades National Park causing water ponding and extended

-DRAFT-
Minimum Water Level Criteria

hydroperiods at the south end of WCA-3A. Both of these conditions are considered harmful to Everglades plant communities and wildlife habitat (Zaffke, 1983).

Holeyland and Rotenberger Wildlife Management Areas.

Physical Characteristics. Together, these two wildlife management areas comprise approximately 59,000 acres consisting of sawgrass and sawgrass/brush and tree islands (**Figure 1**) These areas are state owned and are managed by the Florida Game and Fresh Water Fish Commission for deer, hog and waterfowl hunting. Wading birds and a host of other non-game species of Everglades wildlife also utilize the area.

Major Issues. The Holeyland and Rotenberger Wildlife Management Areas have been identified as areas in need of hydrologic restoration. Similar to northern WCA-3A, the Holey Land and Rotenberger tracts have experienced excessive drying, repeated muck fires, soil subsidence and severe damage to tree islands resulting from lower water levels, soil oxidation and wildfires. Drier conditions have allowed Everglades wetland communities to be replaced by woody terrestrial species such as salt bush and wax myrtle. Diversion of nutrient-enriched canal water has also allowed cattails to replace native vegetation. In 1983, a Memorandum of Understanding was entered into by the DEP the Board of Trustees of the Internal Improvement Trust Fund, the FGFWFC, and the SFWMD to establish a process for the implementation of a plan to restore Everglades values associated with the Holeyland/Rotenberger Tracts and provide for the establishment of water regulation schedules that will simulate the natural hydroperiod. In June 1990, the District and the FGFWFC entered into an agreement detailing the initial operational schedule for the Holey Land will improve hydroperiods for both the Holey Land and WCA-3A (SFWMD, 1992).

Everglades National Park.

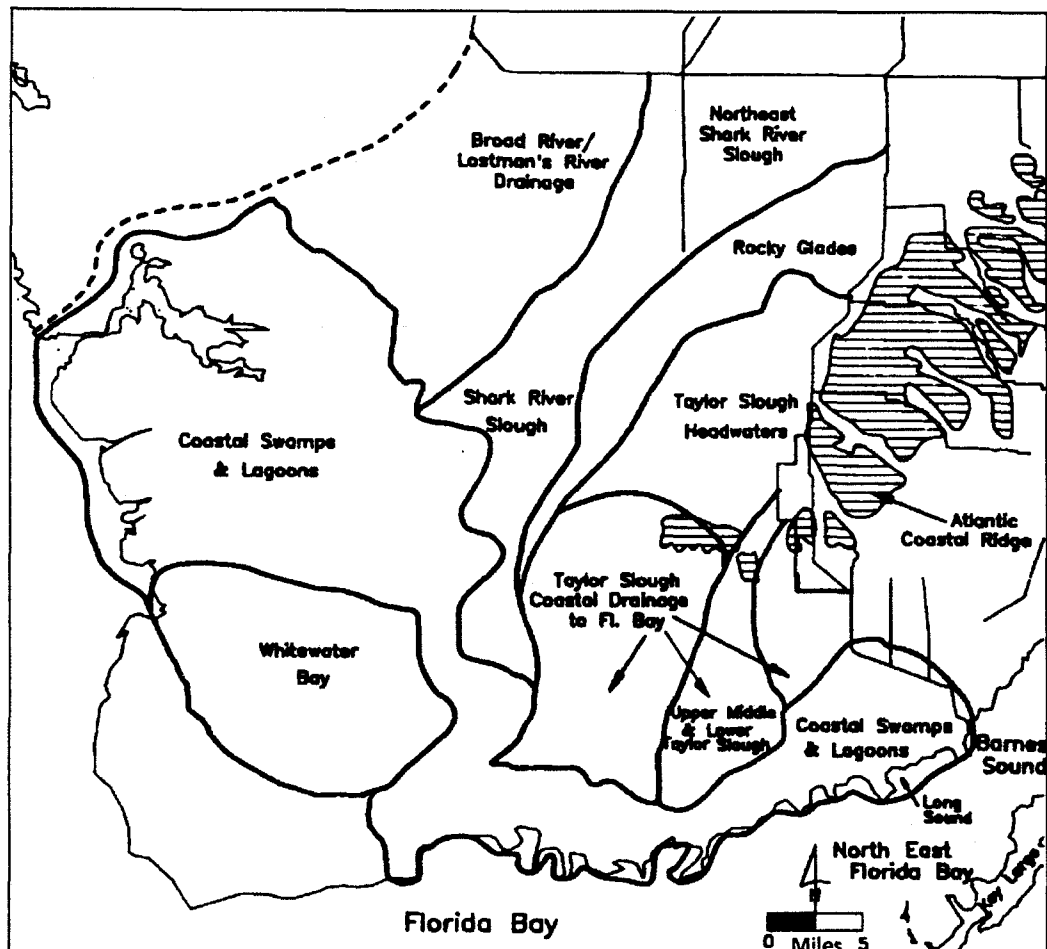
Physical Characteristics. Everglades National Park (ENP) encompasses 2,150 sq. mi. of freshwater sloughs, sawgrass prairies, marl-forming wet prairies, mangrove forests and saline tidal areas located at the southern end of the Florida peninsula (**Figure 1**). The topography is extremely low and flat, with most of the area below 4 ft. NGVD, while highest elevations (6-7 ft. NGVD) occur in the northeastern portion of the Park. Schomer and Drew (1982) recognized five physiographic subzones located within ENP. These include: (1) Shark River Slough, (2) the Rocky Glades, (3) the Broad River/Lostmans River, (4) coastal mangrove swamps and lagoons, and (5) the Cape Sable area as shown in **Figure 3**.

Everglades National Park was formally established by Congress in 1934 to preserve the unique ecology of the Everglades. It was designated by the United Nations as a World Heritage Site in 1979. It has also been named as a Federal Wilderness Area, an International Biosphere Reserve, and a Wetland of International Significance. Today ENP represents the second largest national park in the United States and is also one of the nation's ten most endangered parks.

Major Issues. The quantity, quality, distribution and timing of water flows into the Everglades National Park must be sufficient to maintain and restore the full abundance and diversity of the native floral and faunal communities throughout the Park. Water supply is critical to the continued survival and function of ENP and Florida Bay. Changes in the distribution, timing, and volume of water inflows to

-DRAFT-
Minimum Water Level Criteria

Figure 3. Hydrologic and Physiographic Provinces of the ENP Study Area.



Source: Modified from Schomer and Drew, 1982; Davis 1943a; White, 1970; Puri and Vernon, 1964

ENP and subsequent changes in hydroperiod have been linked to the decline in the Park's biological resources.

Shark River Slough.

Physical Characteristics: This area of Everglades National Park consists of a broad southwesterly arc of continuous wetlands, interspersed with sawgrass strands, open water sloughs, wet prairies, and tree islands extending from Tamiami Trail to the mangrove estuaries of Florida Bay (Figure 3). Underlying soils are moderate to shallow depth Loxahatchee peat. Shark River Slough occupies the center of the Everglades trough and has been described as a wide, slightly concave depression in the underlying limestone (White 1970). The slough represents the principle watershed for ENP and provides the primary source of freshwater inflow for downstream Florida Bay estuaries.

Management Issues: Uncontrolled flow to Shark River Slough was impeded by construction of the first east-west road (Tamiami Trail) and borrow canal built across the Everglades in 1928. Construction of the eastern perimeter levee and impoundment of the upstream water conservation areas as part of the C&SF Project essentially eliminated natural sheet flow to Shark River Slough by the mid 1950's.

-DRAFT- **Minimum Water Level Criteria**

Current flow patterns to ENP are highly influenced by upstream management of the WCAs and pumping of agricultural and urban drainage canals to the north and east. Water level declines have occurred throughout the Park, with major declines occurring along the eastern Park boundary in NE Shark River Slough, the Rocky Glades and northern Taylor Slough. During wet years, western Shark River Slough receives large regulatory releases from the upstream WCAs. These high flows substantially alter natural water patterns and transform the area from a transitional marl-forming wetland to the main flow way. Reintroduction of sheet flow and restoration of more natural water depths and hydroperiods within eastern and western Shark River Slough is a primary goal of the rainfall delivery plan for ENP.

Southern Marl-Forming Marshes.

Physical Characteristics: These wetlands are characterized by the formation of marl soils (also known as calcitic mud). Marl is formed by the precipitation of calcite by blue-green algae in submerged algal mats (periphyton) under shallow water/short hydroperiod conditions. Marl-forming marshes occur on the eastern and western margins of Shark River Slough, as well as in Taylor Slough and the Rocky Glades (**Figure 3**). These wetlands occur at a slightly higher elevation than Shark River Slough and exhibit corresponding shallow water depths and shorter hydroperiods. These communities have also been called the southern coastal marsh prairies (Davis 1943), southeast saline Everglades (Egler 1952), marl Everglades, marl prairies (Harper 1927; Werner 1975; Olmsted and Loope 1984), *Muhlenbergia* prairies (Olmsted *et al.* 1980) and southern marl marshes (Davis *et al.* 1994). The dominant vegetation is muhly grass and sawgrass.

Management Issues: Agricultural and urban development in the east Everglades has resulted in a direct loss of marl-forming wet prairies through conversion of marshes to farmland and housing projects. Construction of the C&SF Project and the South Dade Conveyance System has resulted in compartmentalization of the remaining marl prairie/Rocky Glades wetland system through a network of levees and canals designed to drain the area during wet periods. This water management system has altered hydropatterns and lowered water tables throughout the eastern portion of ENP and reduced flows to Florida Bay.

Presently, large areas of the Rocky Glades and adjacent marl prairies remain dry under average rainfall conditions, as compared to 7-10 months inundation under natural conditions. Shortened hydroperiods reduce wetland aquatic productivity, reduce fish and invertebrate populations, which in turn limit foraging opportunities for wading birds and other Everglades wildlife. Lowered water levels and shortened hydroperiods also alter Everglades fire regimes and allow invasion by woody plants, exotics and other terrestrial species.

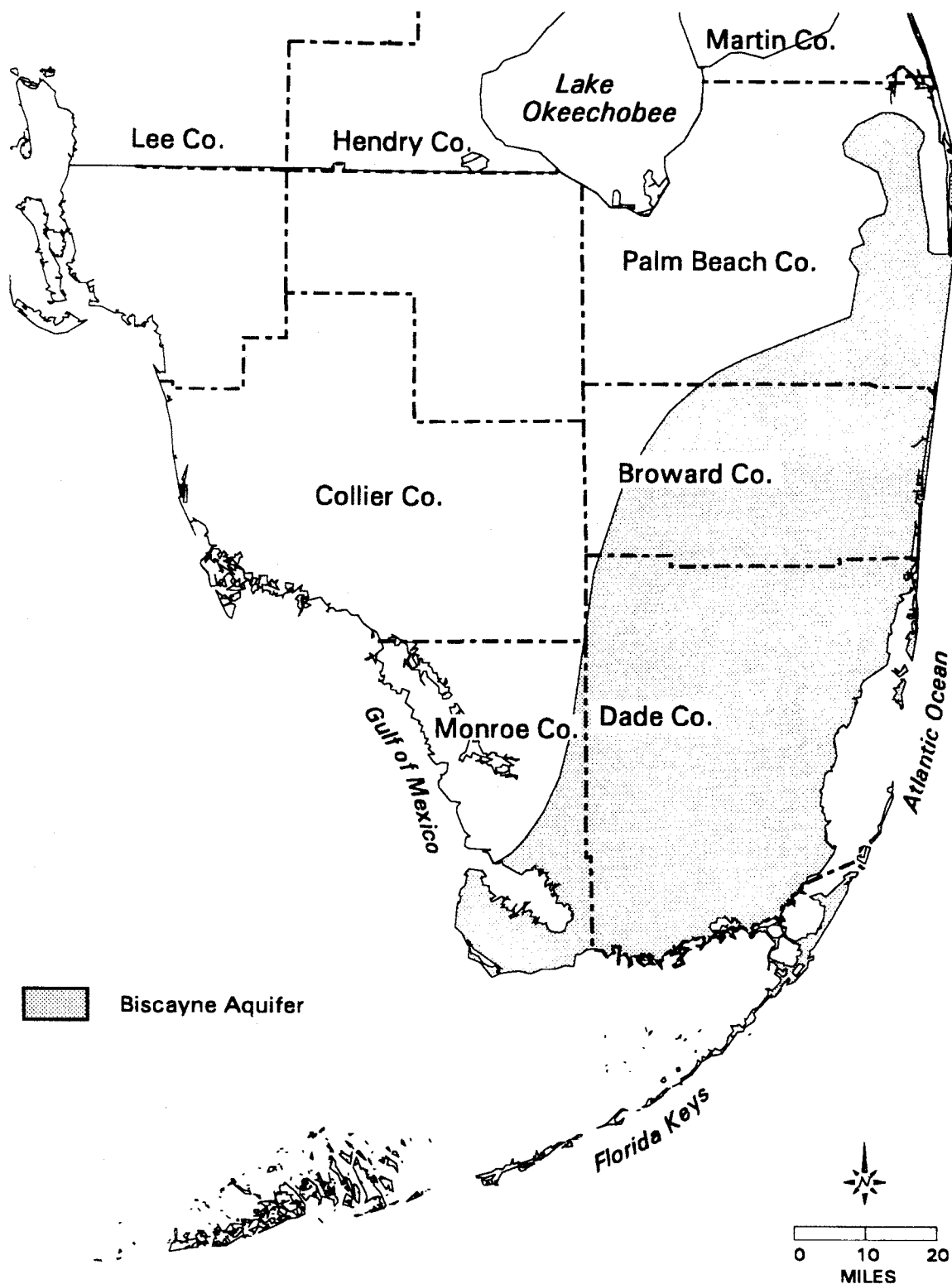
3. Coastal Biscayne Aquifer

Major Features.

The principal groundwater resources for the Lower East Coast planning area are the surficial aquifer and Biscayne Aquifer. These two groundwater systems provide most of the fresh water for public water supply and agriculture within the study area. The Biscayne Aquifer is an unconfined aquifer and a component of the surficial aquifer system underlying most of Southeast Florida as shown in **Figure 4**. These groundwater systems provide:

**-DRAFT-
Minimum Water Level Criteria**

Figure 4. Location and Extent of the Biscayne Aquifer System in South Florida.



-DRAFT- **Minimum Water Level Criteria**

- a major source of drinking water for more than 3 million people living in urban areas along Florida's east coast.
- a source of water for local wells, canals, and lakes.
- a major source of irrigation water for agriculture.
- a source of water to replenish regional wetlands and provide base flow to estuaries such as Biscayne Bay and Florida Bay.

The Biscayne aquifer is composed of units and formations principally deposited during the Pleistocene epoch, or "Great Ice Age." This interval of geologic time was a period of climatic instability where great glaciers would advance and retreat across the continents. As the glaciers advanced, sea level declined and large areas of South Florida became exposed as dry land. Deposition during this time occurred due to dune building and formation of freshwater limestones. As the glaciers melted, sea levels increased and eventually submerged the southern peninsula, creating a highly productive, shallow marine environment. During this time period, marine deposits dominated the composition of the Biscayne aquifer. Typical marine deposits from these high sea level stands occur throughout South Florida and include the coral limestones on Key Largo and the oolitic ridge along the coast (Hoffmeister, 1974).

The major geologic deposits that comprise the Biscayne aquifer include: Miami Limestone, the Fort Thompson Formation, 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, these zones would also be considered part of the Biscayne aquifer if the thickness exceeds 10 feet (Fish and Stewart, 1991).

The Biscayne aquifer is composed of interbedded, unconsolidated sands and shell units with varying thicknesses of consolidated, highly solutioned limestones and sandstones (Shine *et al.* 1989). In general, the Biscayne aquifer contains less amounts of sand and a greater percentage of solutioned limestone than the Surficial Aquifer System. The Biscayne aquifer is one of the most permeable aquifers in the world and has transmissivities in excess of 7 million gallons per day, per foot of drawdown (Parker *et al.* 1955). Due to its regional importance, it has been designated as a sole source aquifer by the U.S. Environmental Protection Agency under the Safe Drinking Water Act and is therefore afforded stringent protection.

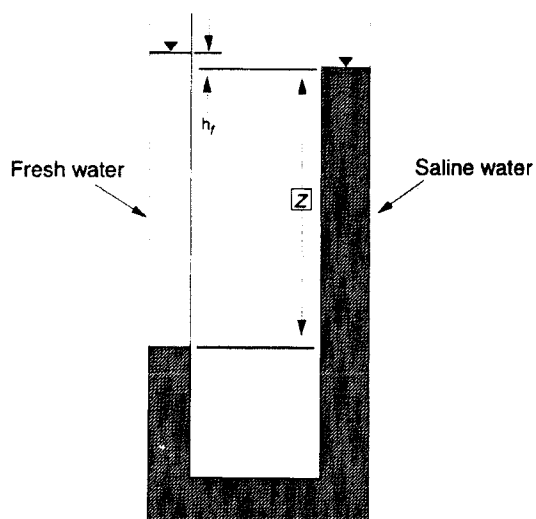
Major Issues.

The principal issue regarding development of minimum level criteria for the Biscayne aquifer is the problem of salt water intrusion, i.e. contamination of the aquifer by salt water. Along the eastern edge of the Biscayne aquifer, both fresh water and salt water are in contact as shown in **Figure 5**.

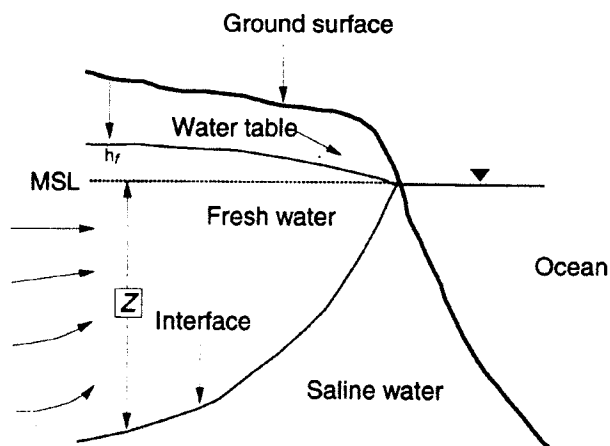
When groundwater levels are lowered inland adjacent to this freshwater/saltwater interface, saltwater potentially can move inland replacing fresh water with saline water. Once the higher density saline water has migrated inland, it remains there for long periods of time and causes a permanent loss of that portion of the aquifer as a source of fresh water. Along the Lower East Coast, lowering of the groundwater table due to overdrainage and increased well field withdrawals has allowed saltwater to invade and contaminate the Biscayne aquifer during periods of drought (Parker *et al.* 1955). Saltwater intrusion of the Biscayne aquifer is considered to be one of the most serious threats to South Florida's coastal water supply.

**-DRAFT-
Minimum Water Level Criteria**

Figure 5. Ghyben-Hertzberg relationship showing freshwater/saltwater interface along the LEC.



Hydrostatic balance
between fresh water
and saline water
illustrated by a U-tube



Idealized sketch of occurrence
of fresh and saline groundwater
in an unconfined coastal aquifer

E. ESTABLISHMENT OF MINIMUM FLOWS AND LEVELS

Three preliminary issues must be addressed in establishing a minimum flow or level for a specific area: 1) What are the priority functions of each water resource to be protected? 2) What is the baseline condition for the functions being protected by applying statutory "Considerations" and "Exclusions?" and 3) What level of protection for these functions is provided by the "significant harm" standard? The following discussion is provided to help understand the legal, policy and technical implications of these issues in establishing minimum levels for Lake Okeechobee, the Biscayne aquifer and the remaining Everglades ecosystem.

1. Water Resource Functions

Each water body, surface water or aquifer serves an array of functions as a water resource. These functions must each be considered in setting the minimum flow or level in light of their importance in achieving sustainability of the water resource. The functions are sometimes competing, such as minimum levels necessary to protect a water body for water supply purposes versus the minimum levels needed for environmental protection. When competing functions exist, the governing board must consider each function, with the associated cause and effect relationships.

Water Resource Definition: State Comprehensive Plan, Section 187.201(8)(b)6., F.S., provides that the water management districts shall:

-DRAFT-
Minimum Water Level Criteria

Establish minimum seasonal flows and levels for surface watercourses with primary consideration given to the protection of natural resources, especially marine, estuarine, and aquatic ecosystems.

"Water resource" is a term of art used throughout Chapter 373, and is most notably within the statute title, "The Florida Water Resources Act of 1972." The water resource functions protected under Chapter 373 are broad, as 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. The need to protect water resources from harm is used in many different places in the statute, including statutory intent (373.016), regulatory implementation (373.219, 373.414), water shortage implementation (373.175, 373.246), enforcement provisions (373.129) and planning requirements (373.026).

Water resource is defined in the District's water shortage rule as "any and all water on or beneath the surface of the ground including natural or artificial water courses, lakes, ponds or diffused surface water and water percolating, standing or flowing beneath the surface of the ground" (40E-1). Water resources include aquatic and wetland as well as the abiotic and biotic components of these systems. The abiotic components include water, its chemical makeup and soils. Biotic components include the plants and animals that comprise and depend on these systems. There are many complex interactions among the water and living components, which determine the essential nature of water resources. See, Florida Electric Power Coordinating Group, Inc, et al., v. SFWMD et al.

The State Water Policy, Section 62-40.405, *Florida Administrative Code (F.A.C.)*, requires that consideration be given to protection of the water resources including natural seasonal fluctuations in water flows or levels, environmental values associated with aquatic and wetland ecology, and water levels within aquifer systems, including 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

This ultimate policy determination, as to which resource functions to consider, is within the Governing Board's purview. This analysis requires a comprehensive look at the resource not only in terms of its own sustainability, but also in terms of its role in sustaining regional water resources. The following is a description of functions of water resources in Lake Okeechobee, the Everglades, and the Biscayne aquifer.

Lake Okeechobee. The definition of significant harm for Lake Okeechobee focuses on the ability of the lake to: a) provide water needed to protect the Biscayne Aquifer from saltwater intrusion during droughts; b) provide water needed to meet supplemental water requirements in agricultural areas and natural systems during droughts; c) protect the extensive (154 sq. mi.) littoral zone marsh community that supports the most diverse portion of the lake's food web; and d) allow navigation

-DRAFT-
Minimum Water Level Criteria

across and within the lake without risk of damage or stranding. The minimum water levels that are proposed in this report provide a means to address these four concerns.

The Everglades. A definition of significant harm for the remaining Everglades (the Water Conservation Areas, Holey Land/Rotenberger Wildlife Management Areas, and Everglades National Park) is based on the effect of reduced water levels on the dominant soils that comprise Everglades wetland communities. Based on technical information provided in this document, scientists conclude that excessive drying of hydric soils (marl and organic peat), which leads to soil oxidation and burning of the soils, constitutes *significant harm* to the resource. For example, water level reductions below those that would normally occur may allow organic peat soils to dry out, oxidize, and burn more often, or more severely, than would occur during normal dry season conditions. Continual loss of these soils is a condition that poses a substantial threat to both the integrity and sustainability of the Everglades ecosystem. Although the exact conditions that make it possible for peat soils to oxidize at a significant rate or burn excessively are not completely known throughout the region, the proposed criteria are based on best available data from a number of different sources. The attempt has been made to define conditions under which increased soil losses are more likely to occur. Under ideal conditions, peat soils may build up (accrete) at a very slow rate of about 0.1 mm per year, more or less.

Biscayne Aquifer. The definition of significant harm for the Biscayne aquifer system, *i.e.* conditions that would make the resource not sustainable, could be based on consideration of many possible sources of damage. In developing minimum flows and levels criteria for the Biscayne aquifer, emphasis was placed on factors that are within the jurisdictional authority of the District, can be controlled and monitored on a regional scale, and can be controlled and tracked using existing District permitting capabilities, structural features, and extensive monitoring network.

Salinity was chosen as the primary criterion of interest for defining significant harm to the Biscayne aquifer for the following reasons: (a) salt water intrusion of the Biscayne aquifer represents a major threat to South Florida's regional water supply system; (b) the District has responsibility to protect the resource from salt water intrusion through operation and maintenance of the structures, pump stations and canals that comprise the Central and Southern Florida Flood Control system; and (c) this parameter is most likely to be directly influenced by changes in aquifer levels.

On a regional scale it is the responsibility of the District to regulate canal levels and salinity structures along the Lower East Coast to prevent saltwater intrusion. Salt water intrusion is often a regional phenomenon that can occur over many miles of coastline and impact numerous users across multiple political boundaries. On a local scale, consumptive uses and drainage systems are regulated by the District in a manner that restricts the net annual inland movement of the salt water/freshwater interface. This movement is influenced by a number of factors including individual or cumulative impacts of drainage projects and/or withdrawals from wellfields. Surface water management systems are operated to ensure that post-development runoff rate does not exceed pre-development runoff rate. Significant harm for the Biscayne aquifer is defined herein as the inland migration of the saltwater/freshwater interface that allows contamination of the surficial aquifer in the vicinity of a public or private water supply wellfield. This may result in either the permanent loss of the wellfield or a significant reduction in production.

2. Identification of baseline conditions for the water resource functions under statutory "Considerations" and "Exclusions"

-DRAFT-
Minimum Water Level Criteria

Once the water resource functions to be protected by a specific minimum flow or level have been identified, as explained above, these functions are then evaluated to determine their applicable baseline or desired condition. These considerations are set forth in Section 373.0421(1)(a), F.S., which allows water management districts, when setting the minimum flow and level, to consider changes and structural alterations that have occurred to a water resource. Likewise, Section 373.0421(1)(b), F.S., recognizes that certain water bodies no longer serve their historical function and that recovery of these water bodies to historical conditions may not be feasible. Allowances are provided to account for the loss of historical functions. These provisions are discussed below to examine their applicability to the minimum levels that are proposed for the Everglades, Biscayne Aquifer and Lake Okeechobee.

"Considerations." Section 373.0421(1)(a), F.S., provides some direction to governing boards to use in establishing baseline or desired conditions for those functions that are to be protected by a minimum flow or level. This statute requires the consideration of changes and structural alterations to watersheds, surface waters and aquifers and the effect such constraints or alterations have had on the hydrology of the area. The important qualifier to this consideration is it cannot be used to allow significant harm caused by withdrawals. This consideration, which relates to the level of protection that is provided by the minimum flow or level, requires the governing board to acknowledge that, due to human activities, some water resources are not performing their historic or natural functions.

In establishing a minimum flow or level for an affected area under this consideration, the governing board may therefore decide, on a well-informed and reasoned basis, not to protect the resource for a purpose it served in the past or to the extent it once functioned. The statute limits, however, the consideration of changes in functions caused by "withdrawals."

"Exclusions." Section 373.0421(1)(b), F.S., also provides "exclusions" for setting minimum flows and levels. These statutory "exclusions" do not apply to the Everglades Protection Area. The Everglades Protection Area is defined in Section 373.4592(2)(h), F.S., as "Water Conservation Areas 1, 2A, 2B, 3A, and 3B, the Arthur R. Marshall Loxahatchee National Wildlife Refuge, and Everglades National Park. The exclusions are only applicable to Lake Okeechobee, Holey Land/Rotenberger Wildlife Management Areas and the Biscayne aquifer, for purposes of this document.

The exclusion that is applicable to Lake Okeechobee and the coastal Biscayne Aquifer, in Section 373.0421(b)1., F.S., first recognizes that "certain water bodies no longer serve their historic hydrologic functions, and that recovery of these areas may not be economically or technically feasible, and could cause adverse environmental or hydrologic impacts." As a result, water management districts may determine that setting a minimum flow or level for such a water body based on its historical condition is not appropriate.

In the most simple terms, this means that where man has changed the functions of a resource to the extent that reestablishment would not be feasible and would cause hydrologic or environmental impacts, the governing board may decide not to restore the previous functions using a minimum flow or level. This reasoning could be applied to Lake Okeechobee, which has had its "natural" historic functions expanded to include those of a regional water supply/flood control reservoir for South Florida. Similarly, the Biscayne aquifer has been altered as a result of drainage and development along Florida's Lower East Coast. The levee around Lake Okeechobee

***-DRAFT-
Minimum Water Level Criteria***

was built to prevent flooding of neighboring areas, especially during hurricanes. Thus, the natural extent and hydrologic properties of the lake have been altered. Restoring the lake to its historic extent and hydrologic condition would undoubtedly have extreme impacts on adjacent land uses, regional water supply and flood control abilities, and would be economically, if not technically, infeasible at this time. Likewise, it would be virtually impossible to restore the original aquifer levels and saltwater interface of the Biscayne aquifer without removing or completely rebuilding existing development and drainage canals.

F. WATER RESOURCE CONSIDERATIONS

During the development of minimum flows and levels criteria for Lake Okeechobee, the Everglades, and the Biscayne aquifer, District staff considered a number of structural changes or alterations that have occurred within these priority water bodies, as well as the constraints such changes have placed on the hydrology of the region. Since the "considerations" in Section 373.0421(1)(a), F.S., adequately address baseline conditions of the Biscayne aquifer and Lake Okeechobee, District staff does not consider that the "exclusions" established in subsection (1)(b) of Section 373.0421, F.S. should apply. Changes, alterations, and constraints on these resources, as covered by the statute, include the following:

1. Lake Okeechobee

- Historic water levels for the lake were estimated to range between 16 and 21 feet NGVD. Early drainage efforts lowered the lake connecting it to the Caloosahatchee River. Catastrophic hurricanes of the 1920's and 1940's prompted the federal government to improve flood protection for the region. In 1948 Congress authorized construction of the Central and Southern Florida Project (C&SF Project) which included impoundment of the lake with the 38 ft. NGVD Herbert Hoover Dike. This structure was completed in the 1960's resulting in the regulation of all lake inflows and outflows with the exception of Fisheating Creek.
- The C&SF project recognizes the lake as a multipurpose regional resource. Its authorized project purposes included flood control, irrigation, municipal and industrial water supply, enhancement of fish and wildlife, navigation, and recreation.
- To maintain an acceptable level of flood protection for communities that surround the lake, water levels during the hurricane season must be maintained at safe levels (less than 16.5 ft. NGVD) that will not threaten the structural integrity of the levee system.
- Another constraint placed on the lake is the amount of water that can be stored for water supply purposes. When lake levels fall below 10.5 ft. NGVD, structural limitations of the lake's outlet structures makes it increasingly difficult to withdraw water to send to downstream users and protect the coastal aquifer from the threat of saltwater intrusion. Theoretically, 9.5 ft NGVD represents the level below which water can no longer be withdrawn from the lake to send to the Lower East Coast.
- In its original condition, the lake was considerably larger than it is today and consisted of an extensive littoral marsh system extending to the north, west and south of the lake. Construction of the levee system (Herbert Hoover Dike) around the lake and the lowering of lake levels from a maximum of 20 ft. to 17 ft. NGVD

-DRAFT-
Minimum Water Level Criteria

effectively isolated thousands of acres of marsh, creating a new littoral zone/marsh community in areas where it had not previously existed.

- A variety of regulation schedules have been implemented on the lake to meet C&SF Project objectives. In 1978 the regulation schedule was raised to a 15.5 - 17.5 ft. regulation schedule to obtain increased water storage capacity. In 1991 an interim regulation schedule was developed to better protect downstream estuaries from harmful lake regulation schedule discharges. A reevaluation of this schedule is currently underway by the USACE.

2. Water Conservation Areas

- Construction of the C&SF Project coupled with large-scale urban and agricultural development of the lower east coast have isolated large segments of original Everglades from the natural system by canals and levees. More than half of the original system has been lost to drainage and development (Davis and Ogden, 1994). Today, these developed areas support a variety of land uses, ranging from intensively managed agriculture in the north (Everglades Agricultural Area) to rapidly spreading urban areas located east of the WCAs.
- Loss of more than half of the original Everglades system to drainage and development has placed a fundamental limitation on the system's capacity to support populations of Everglades wildlife (wading birds, alligators, panthers) that once inhabited the area in much larger numbers.
- The three WCAs are now managed as surface water reservoirs. As part of the C&SF Project, these areas serve multipurpose functions including: (a) flood control for excess water discharged from Lake Okeechobee, the Everglades Agricultural Area and coastal urban areas; (b) recharge coastal groundwater levels to prevent salt water intrusion; (c) supplemental water supply for agriculture, municipal and industrial use; (d) water supply for Everglades National Park; (e) enhance fish and wildlife habitat, and (f) public recreational uses.
- The WCAs no longer receive overland sheetflow derived from upstream rainfall or overflow from Lake Okeechobee. These areas now depend to a large extent on runoff from the EAA and flood releases from Lake Okeechobee. These discharges have significantly altered the volume, timing, distribution and quality of water discharged into the WCA system. This altered flow regime and degraded water quality has resulted in loss or degradation of native Everglades plant communities and associated wildlife habitat.
- Construction of levees and canals have impounded large areas of the WCA marsh resulting in the loss of natural overland sheet flow, over drainage of some areas and excessive flooding in other areas (USACE, 1994). Over drainage has allowed native plant communities to be replaced by terrestrial woody vegetation and introduced exotics such as melaleuca, Australian pine and Brazilian pepper.
- Construction of the four major canals (North New River, Miami, Hillsboro and West Palm Beach canals) through the central portion of the Everglades has resulted in over drainage of large areas (e.g., northern WCA-3A). These canals have reduced water depths and altered hydroperiods, reduced soil elevations and formed "subsidence valleys" along the axis of the major canals. Construction of

-DRAFT-
Minimum Water Level Criteria

1. Consumptive Use Permitting Role: Harm Standard

The resource protection criteria that are used for consumptive use permitting are based on the level of impact that is considered to be *harmful* to the water resource. These criteria are applied, for varying resource functions, to establish the range of hydrologic change that can occur without incurring harm. The hydrological criteria include level, duration and frequency components and are used to define the amount of water that can be allocated from the resource. Saltwater intrusion, wetland drawdown, aquifer mining, and pollution prevention criteria in Chapter 40E-2, F.A.C., all together define the "harm" standard for purposes of consumptive use allocation. These "harm" criteria are currently applied using climate conditions that are represent an assumed level of certainty. The level of certainty used in the Lower West Coast and Upper East Coast Regional Water Supply Plans is 1-in-10, as defined in the District's permitting rules. In addition, the 1-in-10 year drought "level of certainty" is the water supply planning goal that was established in the 1997 legislative changes (Section 373.0831, F.S.). This standard for "harm," as used in the Consumptive Use Permitting process, is considered to be the point at which adverse impacts to water resources that occur during dry conditions are sufficiently severe that they cannot be restored within a period of one to two years of average rainfall conditions. These short term adverse impacts are readily addressed under the consumptive use permit program which calculates allocations to meet demands for use during relatively mild dry season conditions.

2. Water Shortage Role: Serious Harm Standard

Pursuant to section 373.246, F.S., water shortage declarations are designed to prevent "serious harm" from occurring to water resources. "Serious harm," the ultimate harm to the water resources that was contemplated under Chapter 373, F.S., can be interpreted as long term, irreversible impacts to the water resources. In addition, declaration of water shortages will also be used as a tool to prevent significant harm.

When drought conditions exist, water users, typically for irrigation or outside use, increase the amount of withdrawals to supplement the water available from rainfall. These increased withdrawals increase the potential for serious harm. Generally, the more severe the drought, the more supplemental water is used.

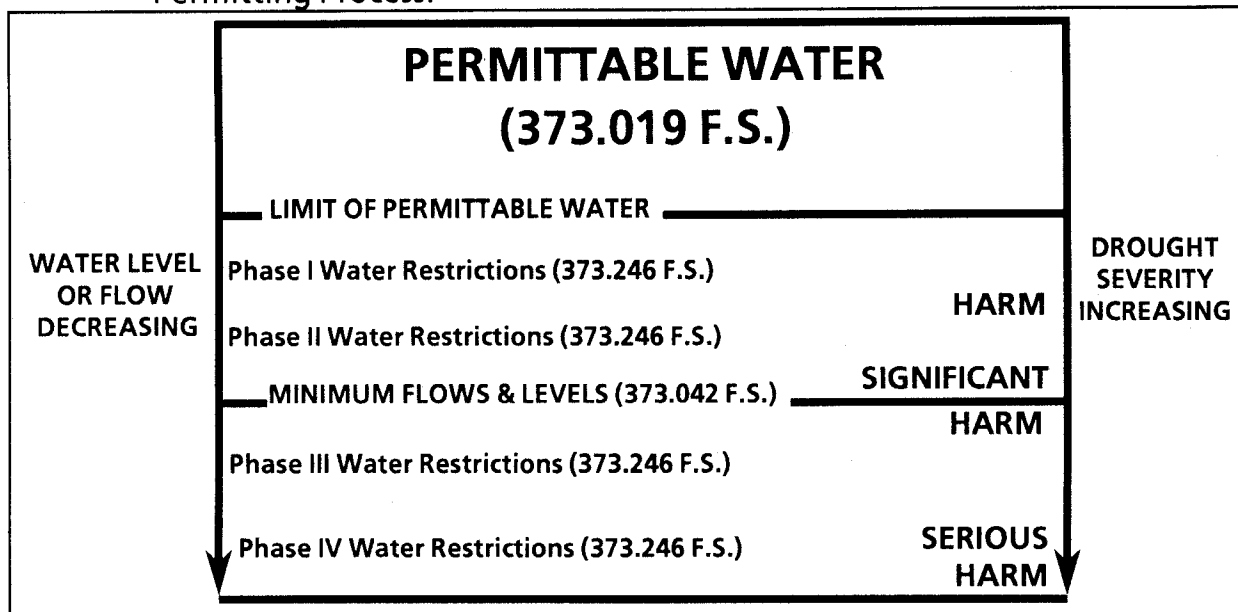
3. Comparison of Significant Harm to Consumptive Use Permitting & Water Shortage Standards

Where does the "significant harm" standard lie in comparison to the consumptive use permitting and water shortage standards? The plain language of the standards of "*harm*" versus "*significant harm*," although undefined by statute, implies that the minimum flow or level criteria should consider impacts that are more severe than those addressed by the consumptive use permitting standard but less severe than the impacts addressed by the "serious harm" standard in the water shortage program. The conceptual relationships among no harm, harm, significant harm and serious harm are shown in **Figure 6**.

The technical discussions in Section III of this report only identify the scale of water resource impacts associated with significant harm that are required to establish minimum water levels for the Everglades, Biscayne aquifer and Lake Okeechobee.

-DRAFT-
Minimum Water Level Criteria

Figure 6. Conceptual Relationship among the Terms, No Harm, Harm, Significant Harm and Serious Harm as used in the District's Consumptive Use Permitting Process.



H. DEFINITION OF SIGNIFICANT HARM TO THE WATER RESOURCES OF THE AREA

Based on the above considerations, the definition of significant harm of the water resources of the areas is:

***Significant harm** is defined as a loss of specific water resource functions that take multiple years to recover, that result from a change in surface water or ground water hydrology.*

The following section (Section II) of this report describes the methods that were used to establish significant harm criteria for the the Everglades, Lake Okeechobee and the Biscayne aquifer. Section III describes the specific hydrologic criteria, with frequency, duration and depth components, that were developed to indicate the point at which significant harm occurs and includes an analysis of the specific relevant factors and implications of the proposed definition of "significant harm." Conclusions and recommendations are presented in Section IV and the literature cited is listed in Section V. A number of technical appendices (in a separate volume) are included that provide more detailed descriptions and analyses of available data, literature, and issues raised during the review process.

-DRAFT-
Minimum Water Level Criteria

II. METHODS

A. METHODS USED TO DEVELOP MFL CRITERIA FOR LAKE OKEECHOBEE

Minimum water level criteria for Lake Okeechobee were based on four sources of information: historical water level data from a designated reference period; review of the District's current drought management plans for Lake Okeechobee; results from recent ecological research; and output from GIS studies of the relationship between lake levels and littoral zone inundation.

1. Historical Water Levels.

The years from 1953 to 1972 were used as a historical reference period for the lake. Water level fluctuations during those 20 years gave rise to the current littoral plant communities (documented by Pesnell and Brown, 1973) that are viewed as optimal (minimally-impacted) for the diked lake ecosystem. Using daily water level measurements obtained from the SFWMD hydrologic data base DBHYDRO, we determined the range of water levels that occurred during 1953 to 1972. Minima generally were above 12 ft NGVD, however, during the 20 year period of record, water levels fell below 11 ft NGVD on three occasions. Review of the entire 63 year period of record (1932-1995) recorded water levels dropping below 10 ft. NGVD only once in 1981 (See **Figure 10**).

2. Review of Drought Management Plans for Lake Okeechobee.

The amount of rainfall that falls in South Florida from year to year is highly variable and in some years can result in drought conditions. Historical records show that when lake levels fall below 11.0 ft. NGVD, severe water shortage restrictions occur along Florida's lower east coast. Once below 11.0 ft., these levels decline rapidly affecting the District's ability to deliver water to downstream users as well as affecting the ecology of the lake. As water levels drop below 10.5 ft. NGVD, structural limitations of the lake's outlet structures makes it increasingly difficult to withdraw water from the lake to send downstream to protect lower east coast wellfields against saltwater intrusion. In 1982, the District adopted a water management strategy designed to avoid extreme drawdowns of the lake that impact South Florida's reserve water supply. This plan provides (a) a balanced water allocation strategy for all users to avoid severe drawdowns of the lake; (b) a method for holding water in reserve for later high demand periods; and (c) a defined minimum level for holding water in reserve to protect coastal wellfields from the threat of saltwater intrusion. As part of the development of MFLs for Lake Okeechobee, District staff reviewed the following publications: Staff Manual for the Management of Water Shortages (SFWMD, 1987), and Supply-side Management Plan for Lake Okeechobee (Hall, 1991) to identify how water is currently managed in the system to ensure that adequate water is held in reserve to prevent significant harm to the water resources of Lake Okeechobee and the Biscayne aquifer.

3. GIS Studies.

Geographical Information System (GIS) maps showing the percent of the littoral zone inundated at different lake stages were also reviewed to provide support for the hypothesis that water levels falling below the minima would result in exposure of large portions of the marsh. At water levels of 15, 14, 13, 12, 11, and 10 ft NGVD, the percent of marsh exposed was calculated and reported, both in tabular and graphical form. Regions shown to become dry at low water levels were considered in terms of

-DRAFT- Minimum Water Level Criteria

the present locations of native and exotic plants (Aumen & Wetzel 1995), in order to assess the opportunity for exotic plants to expand into native plant-dominated areas. As an example, Moonshine Bay presently supports a large *Eleocharis* community that is habitat for the endangered snail kite. This community was deemed "at risk" under prolonged low water levels (< 11 ft NGVD) because nearby there is a large stand of Torpedo Grass that tolerates dry conditions.

4. Recent Ecological Research.

To document the relationship between the proposed minimal level criteria and harm to the ecosystem, we considered the results of ecological research performed as part of the Lake Okeechobee Ecosystem Study (Aumen and Wetzel 1995). Data from this study provides information on the effects of water level variation on selected ecosystem components (wading birds, fish, and vegetation).

B. METHODS USED TO DEVELOP MFL CRITERIA FOR THE EVERGLADES

Minimum water level criteria for the natural systems of the Everglades Protection Area were based on three primary sources of information: (a) scientific literature; (b) results obtained from the Natural System Model (version 4.5), and (c) a review of historical water levels and fire records. The processes used to review and integrate this body of information are described below.

1. Literature Review.

A review of scientific and technical literature was conducted to compile and summarize available information that describes the ranges of water levels that occur during drought conditions within the Everglades and other peat and marl based wetland systems. The search was limited primarily to include studies conducted within South Florida to document minimum water levels recorded during low rainfall periods and their subsequent impact on wetlands. These data were synthesized into tables to show ranges of minimum water levels, the duration of each event and return frequency. A computer bibliographic search (Dialog Information Service) was also conducted using the following key words: *organic soils, marl soils, soil subsidence, Everglades water levels, Everglades hydroperiod, changes in Everglades plant communities, fire in the Everglades, effects of drought in the Everglades, and minimum water levels*. Results of this search are included in the list of references provided in **Appendix E** of this report. Recent technical publications produced by the SFWMD and the South Florida Research Center at Everglades National Park were also reviewed. The final product includes a list of technical publications that discuss minimum water levels observed in the Everglades Protection Area as well as documented events where environmental impacts have been observed as a result of overdrainage of the system.

2. Review of Historical Water Levels and Fire Records.

Fire is a natural force that has shaped the Everglades ecosystem. Periodic fires prevent the natural succession of fire adapted species such as sawgrass or maidencane to woody or bush vegetation. Communities maintained by fire are called fire subclimax communities. Conversely, severe fires that consume peat and damage wetland plant communities can result in ecological impacts that last from 3 to 10 decades (DeAngelis, 1994). Therefore, a potential increase in the frequency of severe fires within the Everglades, due to lowered water levels or shortened hydroperiods relative to historic conditions, is of concern. In this study, District staff reviewed

-DRAFT-
Minimum Water Level Criteria

historical hydrologic conditions at key water management locations located within the EPA. These data were compared with available fire records provided to the District by the Florida Game and Fresh Water Fish Commission as well as those obtained from the published literature (e.g., Loveless, 1959; Robertson 1953; Craighead 1971; Gleason and Stone 1974; Schortemeyer 1980; Wade et al. 1980; Taylor 1981; Zaffke 1983; Alexander and Crook 1984; Gunderson and Synder 1994).

3. Modeling.

The Natural Systems Model (NSM) version 4.5, developed by SFWMD staff, was used as a means to estimate water depths and return frequencies (hydroperiods) for minimum water level conditions in the remaining Everglades system. The NSM provides a means to simulate the hydrologic response of the pre-drainage Everglades using recent (1965-1996) records of rainfall and other climatic inputs. The NSM simulates the hydrologic conditions of the natural system prior to the influence by man, as this unaltered system would have responded to recent climatic (rainfall) conditions. This modeling approach was used for two reasons: (a) historical hydrologic data for the 1800's or early 1900's do not exist (hence there is no means to directly calibrate the model), and (b) the use of recent historical information allows comparisons to be made between the response of the natural system and that of the current managed system under identical climatic conditions. In this sense, the NSM is a useful planning tool for understanding how the natural system originally worked without the canals, levees and water management structures in place.

In the NSM, the canals, structures and levees are replaced with the rivers, creeks and channels that discharge water from the interior of the peninsula toward the coast through a simulated version of the "transverse glades," which extended along the coast in Broward and Dade Counties. Historical sheet flow characteristics, which were present prior to development of South Florida, are used to convey water through the marshes. The vegetation and topography used by the NSM are based on estimates of pre-drainage conditions. Historical vegetation is based on a map originally developed by Davis (1943) and later updated and modified by Costanza (1975). Historical topography is based on our current knowledge of ground level surfaces in the Everglades using best available historical information (e.g., ground levels recorded during construction of the primary canal system through the Everglades). In areas where the historical topography is higher than current conditions, surface water ponding depths are presented as adjusted or "normalized" to ground level for both the current managed system and the NSM.

In this study, the NSM was used to estimate the depth, duration and return frequency that water levels fell to minimum levels during drought periods in the predrainage Everglades. These analyses focused on locations that represent present day water management gages located within the Water Conservation Areas and Everglades National Park. Key gages selected for this analysis are shown in **Figure 13**, Section III of this report and include: the 1-7 gage located in the central portion of WCA-1; the 2A-17 gage located within the central portion of WCA-2A; the 2B-21 gage located at the south end of WCA-2B; the 3A-2 (deer gage) and 3A-3 gages located within northern WCA-3A; the 3A-4 and 3A-28 gages, located within southern WCA-3A; the 3A-SE gage located in the southeast portion of WCA-3B; and NP-201, G-620, NESRS-2, NP-33, NP-36, NP-34, NP-38, G-1502, G-1251, G-596 and NP-207 gages located in Everglades National Park.

The NSM was first developed in 1989 by District staff (Perkins and MacVicar, 1991) and has been revised and updated. Version 4.1 of the NSM was adopted by the

-DRAFT-
Minimum Water Level Criteria

Scientific Working Group (1995) as the best available tool to simulate hydrologic response of the natural Everglades. Further refinements were made to the model to produce the current release (version 4.5).

C. METHODS USED TO DEVELOP MFL CRITERIA FOR THE BISCAYNE AQUIFER

Development of minimum water level criteria for the Biscayne Aquifer were determined from three primary sources of information: (a) a review of the available literature; (b) review and evaluation of historical water levels and water quality data from area monitoring wells; and (c) a review of various wellfield models to determine the relationships among groundwater levels, aquifer characteristics and the degree of salt water intrusion that could be expected during a major drought period.

1. Literature Review.

A review of the available literature was conducted to compile and summarize existing information that describes salt water intrusion within an unconfined aquifer system. This review was primarily limited to southeastern Florida, but the general mechanics of salt water intrusion were also evaluated. Pertinent articles reviewed are cited in the text and included in the literature cited section of this report. The focus of the review was to understand the mechanics of salt water intrusion within the Biscayne aquifer and to determine if a scientifically defensible relationship exists among groundwater levels, aquifer characteristics, and the degree of salt water intrusion. Water level and water quality data were also analyzed for more than 500 monitoring wells located throughout the study area. Information included United States Geological Survey (USGS) data, the SFWMD SALT data base, and various consulting reports and articles.

2. Data Analyses and Modeling Approaches.

To determine a minimum level that should be maintained in the Biscayne aquifer to prevent further inland migration of the saline interface, four separate approaches were used: (1) an evaluation of water quality and water level data from all available monitoring wells in the region and canal stage data from coastal water management structures; (2) an evaluation of the applicability of the Ghyben-Herzberg relationship to setting salt water intrusion protection levels; (3) an evaluation of the influence of the maintained canal levels on coastal aquifer water levels using the South Florida Water Management Model (SFWMM) to evaluate; and (4) an evaluation of various canal stages and their influence on the position of the saline interface using a two-dimensional solute transport/flow model (SWICHA) to evaluate (Andersen, 1986).

Evaluation of Monitoring Well Data. Water level and water quality data from 500 monitoring wells within the study area were evaluated. Average dry and wet season water levels were determined for each well. In addition, initial, mean, and final chloride concentrations were noted for each monitoring well to determine: (a) if the saltwater front had reached that monitoring well; (b) if the front was stable, (c) if the front was still moving, and (d) long-term trends. The depth of each well was also noted. Stage duration curves were developed for each coastal control structure. The mean and 84th percentile stages were calculated and the data were then analyzed to determine if there was a relationship between water levels and chloride concentration. The 84th percentile was selected because it statistically represents one standard deviation from the mean. Statistical analyses were completed for a select number of wells to investigate the correlation between well water levels and

-DRAFT-
Minimum Water Level Criteria

chloride concentration. Correlation coefficients, covariance, standard deviation, mean and variance statistics were performed to assist this evaluation.

Evaluation of the Ghyben-Herzberg Relationship. The Ghyben-Herzberg relationship (Todd, 1980) was evaluated to determine its validity for South Florida conditions. **Figure 5** shows the idealized Ghyben-Herzberg model for the fresh water/salt water interface along a coastal aquifer. The Ghyben-Herzberg relationship assumes that the interface exists in a static equilibrium, with a hydrostatic pressure distribution in the fresh water region of the aquifer and stationary salt water (Bear, 1972). The equation developed by Ghyben and Herzberg to simulate their observations is:

$$h_s = h_f \times 40$$

where: h_s = depth to salt water interface (feet below sea level)

h_f = fresh water head (feet NGVD)

In evaluating the applicability of this method to South Florida conditions, several variables are known. These include historical water level and chloride concentrations from a number of monitoring wells along the coast, the depth of each monitoring well, and the depth to the base of the Biscayne aquifer. The theoretical fresh water head necessary to prevent salt water intrusion is based on calculation of the Ghyben-Herzberg relationship for each selected monitoring well. The depth of the monitoring well was divided by 40 to obtain the theoretical fresh water head. This value was then compared to actual wet and dry season average water levels recorded for each well. If the actual recorded water level was greater than the theoretical fresh water head, then it was assumed that salt water intrusion would not occur. If the value was less than the theoretical head, it was assumed that salt water could potentially contaminate the monitoring well. Average and recent chloride concentration data from each well were then used to determine the percentage of wells that could remain as fresh water producing wells and those that might be affected by salt water, as predicted by the Ghyben-Herzberg relationship.

SFWMM Modeling. The South Florida Water Management District maintains over 1,400 miles of canals, levees, and water management structures designed primarily to provide drainage for developed areas along Florida's lower east coast. This extensive canal system (**Figure 7**) also plays an important role in preventing further inland migration of saltwater into the Biscayne aquifer. During times of drought, water is maintained in coastal canals by transporting water from the Water Conservation Areas or from Lake Okeechobee eastward into coastal basins.

Development of minimum flows and levels for the Biscayne aquifer required an understanding of how the canal network influences coastal water level conditions within specific geographic areas. The South Florida Water Management Model (SFWMM) was used to analyze the interaction between the coastal canals and aquifer water levels during times of drought. The SFWMM is a two-dimensional, regional-scale, integrated surface-ground water flow model that simulates the hydrology and water management of southeastern Florida. The model covers an area of approximately 7,600 square miles, and includes the remaining Everglades ecosystem, the urbanized east coast, and agricultural areas located south and east of Lake Okeechobee. The model performs a continuous daily simulation over 26 years (1965-1990) of historical data, including operation of the canal network.

-DRAFT-
Minimum Water Level Criteria

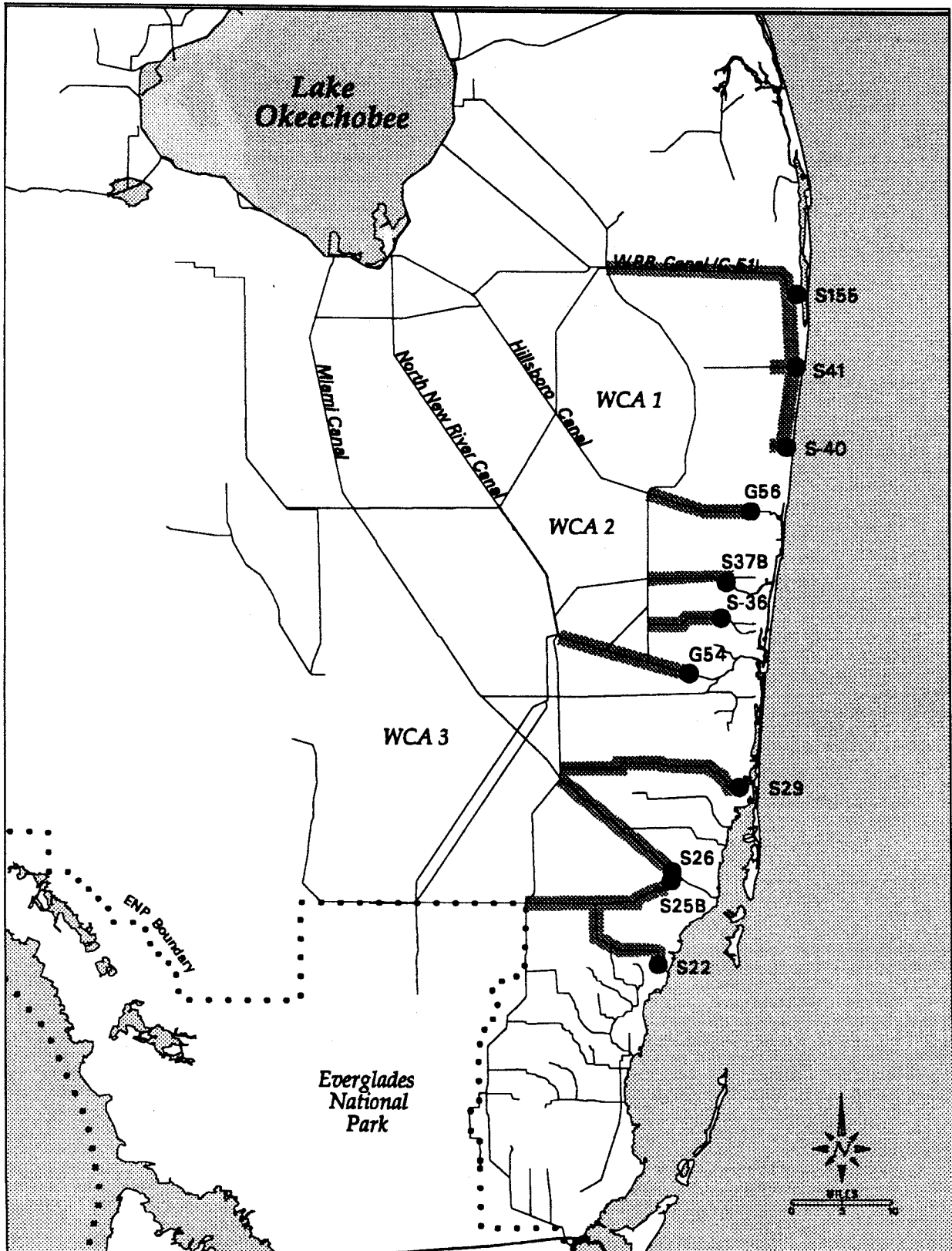


Figure 7. SFWMD coastal canal network indicating key water management canals and structures for maintenance of minimum levels in the Biscayne Aquifer.

-DRAFT-
Minimum Water Level Criteria

In setting minimum flows and levels to prevent saltwater intrusion, it was necessary to evaluate what influence these canals have on water levels within the Biscayne aquifer. To increase our understanding of the relationship between the canal network and aquifer water levels, two separate model runs were simulated using the SFWMM:

- The first simulation consisted of operation of the system under present conditions. That is, coastal canals, which are currently maintained by the regional system during drought periods, continue to receive water from the Water Conservation Area system and Lake Okeechobee during low rainfall years.
- The second simulation evaluated another option in which coastal canals were not maintained for water supply purposes during drought years.

Each scenario used daily climate data for the 26 year (1965-1990) period of record. A water shortage trigger module, developed as part of the Lower East Coast Regional Water Supply Plan was used to record water levels at key monitoring locations along the coast. The water shortage module would predict when water shortage restrictions would be evoked based on water levels near the salt water interface. In general terms, a "Phase 1 water shortage" is anticipated when coastal water levels fall below 1 ft NGVD. Data from 20 key monitoring locations were recorded along the lower east coast of Florida. Results of the maintained canal simulation were compared with results of the non-maintained canal simulation at key monitoring locations to determine the role that the regional canal system played in preventing salt water intrusion within the Biscayne aquifer.

Salt Water Intrusion Modeling. The final method that was used to determine minimum levels for the Biscayne aquifer was to estimate the position of the salt water interface for various local scale modeling scenarios. Preliminary results were based upon two-dimensional cross-sectional modeling of the Biscayne aquifer at various transects along the southeast coast of Florida. Variations of inland water levels and impacts of canal water level changes were analyzed and evaluated. The model that is used to gain a general understanding of local scale salt water intrusion within the Biscayne aquifer is SWICHA, a three-dimensional finite element code developed by Huyakorn, Mercer and Andersen (1986) for analyzing seawater intrusion in coastal aquifers. The SWICHA model allows both two-dimensional cross sectional analysis of salt water intrusion and more elaborate three-dimensional evaluations. In this study, five separate two-dimensional cross sectional models were developed and modified from Andersen's work (1986) for the study area to evaluate various minimum flow and level scenarios.

III. RESULTS -- PROPOSED MINIMUM FLOWS AND LEVELS CRITERIA

The following sections present the minimum flows and levels (MFL) criteria as required in Chapter 373, *Florida Statutes* for Lake Okeechobee, the three Water Conservation Areas, the Holey Land and Rotenberger Wildlife Management Areas, Everglades National Park, and the Biscayne aquifer. Each section provides: (a) a summary of the technical relationships which equate to significant harm for each water body; and (b) a detailed presentation of the proposed MFL criteria with supporting documentation.

A. PROPOSED MFL CRITERIA FOR LAKE OKEECHOBEE

Minimum water level limits need to be established in Lake Okeechobee in order to:

- Reserve water within the lake to maintain a freshwater head in coastal canals that will meet local water supply needs and prevent significant harm from occurring to the coastal aquifer as a result of saltwater intrusion.
- Prevent significant harm from occurring to the ecological resources of Lake Okeechobee including its littoral zone, sport and commercial fisheries and resident threatened and endangered species populations.
- Provide supplemental water supplies for the Everglades Agricultural Area (EAA), the Caloosahatchee, and St. Lucie basins during low rainfall periods.
- Prevent the occurrence of long-term low water stages that restrict navigation and recreational use of the lake by the public.
- Provide water supply for Everglades National Park

For the purpose of this study, **significant harm** is defined as a loss of specific water resource functions that take multiple years to recover, that result from a change in surface water or ground water hydrology.

1. Technical Relationships that Equate to Significant Harm

Relationship Between Lake Levels and Water Supply. Long-term, frequent drawdowns of Lake Okeechobee below 11 ft. NGVD reduces the District's ability to reserve water within the regional system. A reserve supply of water is needed within Lake Okeechobee to meet urban, agricultural, and environmental water needs during periods of below normal rainfall.

Drought Management. To avoid extreme drawdowns that impact South Florida's reserve water supply, the District has developed a water supply management plan for Lake Okeechobee (SFWMD 1987; Hall 1991). This plan was first developed in 1982 and serves as the District's basis for making water management decisions during periods of low rainfall. The primary objective of the plan is to ensure that adequate amounts of water are held in reserve within the lake for later, high demand periods, but is yet responsive to the short-term needs of users who depend on the lake as their primary water source. The plan provides an allocation strategy which parcels out lake water to downstream users based on weekly estimates of water use and demand for various user groups for the remainder of the dry season.

**-DRAFT-
Minimum Water Level Criteria**

This water allocation strategy is based on six critical lake water management zones (**Figure 8**) that require specific actions to be taken once water levels fall within

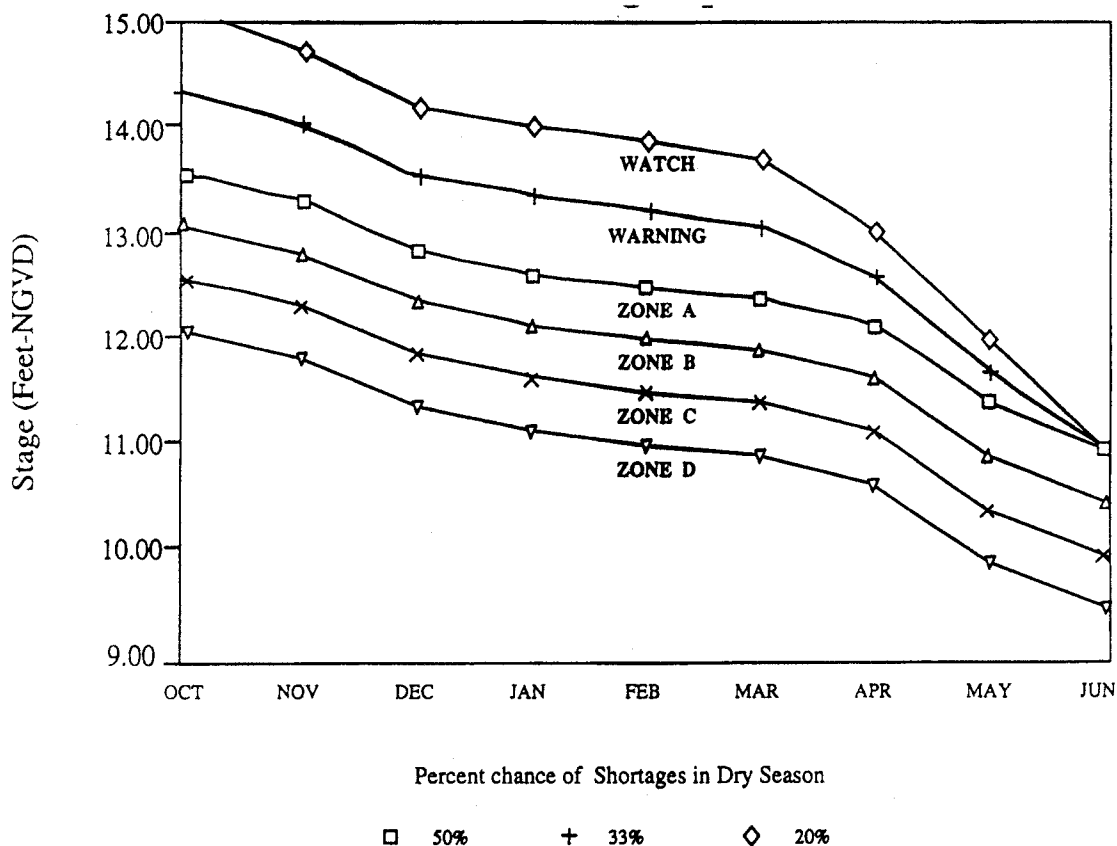


Figure 8. Lake Okeechobee Water Supply Management Zones (after Hall, 1991)

each designated zone. These include a water shortage "watch" zone, a water shortage "warning" zone, and water supply management zones A through D as shown in **Figure 8**. This water allocation plan has been in operation since 1982 and provides (a) a balanced water allocation strategy for all users to avoid severe drawdowns of the lake, (b) a method for holding water in reserve for anticipated high demand periods, and (c) a defined minimum water level target for holding water in reserve to protect coastal wellfields from the threat of saltwater intrusion. For a more detailed discussion of how these management zones are operated during low rainfall periods to maintain coastal groundwater levels, provide irrigation water to the EAA, and meet water supply needs of the Caloosahatchee River and St. Lucie Canal Basins, the reader is referred to the District's Water Shortage Manual (SFWMD, 1987), and the report entitled "Supply-side Management for Lake Okeechobee" (Hall, 1991).

Protection of the Coastal Aquifer. As part of the Central and Southern Florida Project, Lake Okeechobee plays a critical role as a source of freshwater for maintaining coastal groundwater levels to prevent saltwater intrusion of the Biscayne aquifer. During dry periods when freshwater supplies are depleted along the Lower East Coast, freshwater is discharged from interior storage areas such as Lake Okeechobee and the Water Conservation Areas to the coastal canal system. These water releases help maintain a freshwater head within the coastal groundwater aquifer that prevents inland movement of the saltwater front.

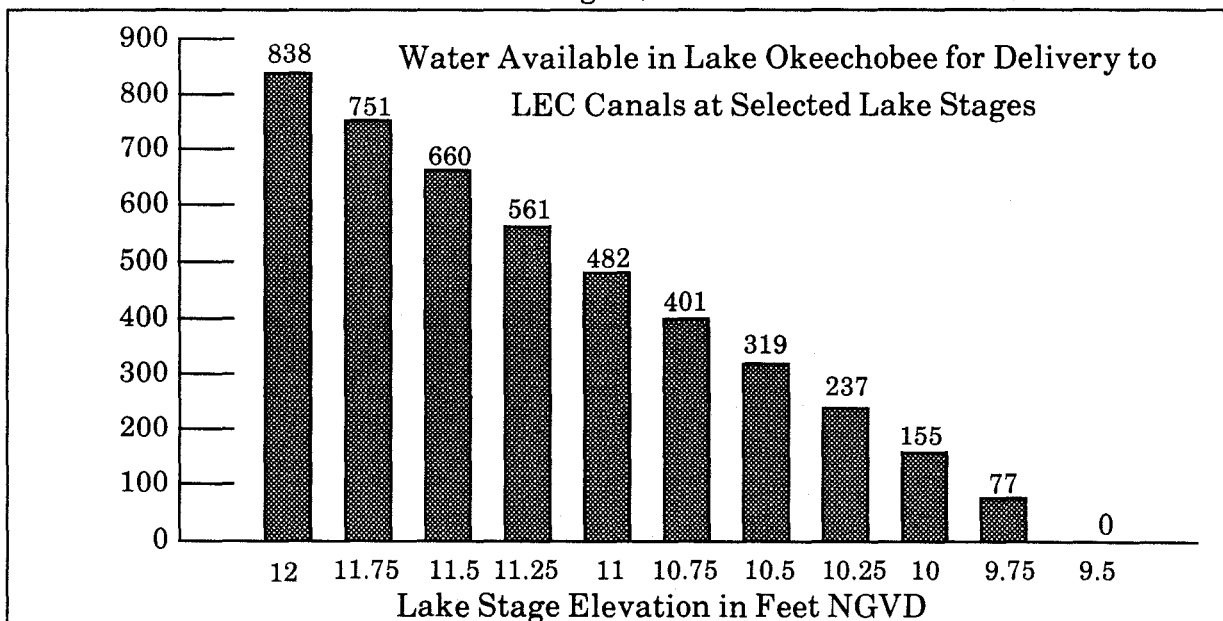
-DRAFT-
Minimum Water Level Criteria

Saltwater intrusion can occur whenever water levels within local canals or the aquifer drop below the elevation of the adjacent saltwater front.

The District's water supply management plan (SFWMD 1987; Hall 1991) establishes 11 ft. NGVD by the end of the dry season (May 31st) as the critical water level planning target for Lake Okeechobee for protection of the coastal aquifer. The 11 ft criterion was selected, in part, based on the need to provide a reserve supply of water within the lake to prevent saltwater intrusion within the coastal aquifer.

Water Supply to the Lower East Coast. Historical records show that when lake levels fall below 11 ft. NGVD, severe water shortage restrictions occur along Florida's Lower East Coast (Hall, 1991). **Figure 9** provides a summary of the relationship between lake stage and the amount of water that can be stored in the lake for delivery to Lower East Coast canals during dry periods. As lake water levels recede below 11 ft. NGVD, these levels decline rapidly affecting the District's ability to deliver water to downstream users. Once water levels fall below 10.5 ft. NGVD, the

Figure 9. Amount of water available in Lake Okeechobee for delivery to LEC Canals at various lake stages (in thousands of Acre Feet).



Source: SFWMD data. Graph based on lake stage/volume relationship

physical limitations of the lake's primary outlet structures come into play making it increasingly difficult to convey water from the lake to coastal canals to protect the Biscayne aquifer and existing wellfields against saltwater intrusion. The 10.5 ft. NGVD elevation generally represents the bottom of the conservation pool for water supply planning purposes. However, no regulations have been established to make this elevation a required point of no withdrawals from the Lake. Instead, the District has established a water conservation policy (i.e., Supply-side Management Plan) which applies a percentage reduction to water withdrawals below the seasonally varying water supply schedule shown in **Figure 8**. This water conservation policy begins in Zone C and extends below elevation 10.5 ft. and sometimes may go as low as 9.5 ft. NGVD. (USACE, 1991). Theoretically, 9.5 ft. represents the level below which water can no longer be withdrawn from Lake Okeechobee due the structural limitations of it's primary outlet structures (**Figure 9**). The lowest stage ever recorded for Lake Okeechobee was in July 1981 when lake levels fell to 9.78 ft. NGVD

-DRAFT-
Minimum Water Level Criteria

during a long-term regional drought. Lake storage below 10.5 ft. provides water for a number of multi-use purposes including water supply, navigation, protection of fish and wildlife and recreation (USACE, 1991).

Water Supply to the EAA, the Caloosahatchee and St. Lucie Basins . During drought conditions, agricultural water needs within these basins are estimated on the basis of weather, soil and crop conditions. At the beginning of the dry season, calculations are made to determine the amount of water in storage and the proportion that is available for allocation. Based on this calculation, water is allocated as a percentage of the flow volume that would be needed to meet normal dry season irrigation demands in each basin. The allocation is adjusted on a monthly or weekly basis to allow for changes in regional and local conditions. The Governing Board has the authority to make adjustments to the allocations based on local circumstances during drought periods (Hall, 1991). Special conditions may apply in the St. Lucie Canal basin during periods when water levels in coastal canals are higher than the stage in Lake Okeechobee. During these times, no additional water can be supplied from the Lake, and water from the basin may in fact, flow back into the lake to enhance regional supplies. Also, in the Caloosahatchee basin, water releases from the lake may periodically be required to improve water quality conditions in the canal that result in algae blooms or saltwater contamination at the S-79 structure (USACE, 1991).

Water Supply for Everglades National Park. Shortly after Everglades National Park was created, it became apparent that the Park was not receiving sufficient freshwater flows during dry periods to maintain viable aquatic ecosystems and protect vegetation and wildlife from damaging fires. In 1970 Congress adopted Public Law 91-282 which provided a minimum water delivery schedule for ENP based on minimum monthly flow requirements. Later, it became apparent that this schedule resulted in unnatural volumes and timing of water flows discharged from the WCAs to western Shark River Slough causing failure of alligator nests, abandonment of wading bird rookeries, and alteration of wetland communities (NPS-SFRC, 1989). In 1984 this delivery schedule was replaced with a water delivery model called the "Rainfall Plan" to provide a more natural timing of water deliveries to ENP (MacVicar 1985; Neidrauer and Cooper 1989). Using this approach, water is discharged into the Park during periods when rainfall is occurring in the upstream watershed. If no rainfall is occurring, then no water is provided. This management method helped address the problem of maintaining more natural cycles of wet and dry season flows to the Park, and also made it easier to meet the water needs of the Park during regional drought conditions. The Rainfall Plan has been proven effective in the reestablishment of more natural hydroperiods and provides better overland flow to Shark River Slough. This plan remains in effect today while other additional improvements are being evaluated (Light and Dineen, 1994) such as the Modified Water Deliveries to ENP Plan, and the C-111 South Dade Project .

Relationship between Lake Levels and Protection of Ecological Resources. This section summarizes the major effects that may result from long-term, frequent drawdowns of the lake below 11 ft. NGVD. **Table F-1, Appendix F** provides a detailed summary of the causes and effects of the impacts as well as a matrix that show the effects of both high and low water stages on the Lake Okeechobee ecosystem.

Minimum water level limits need to be established for Lake Okeechobee in order to prevent significant harm from occurring to the intrinsic ecological and societal values of this water resource. These values were recently identified in a multi-agency

-DRAFT-
Minimum Water Level Criteria

workshop held in March 1997 (Havens and Rosen 1997), and include: (1) a commercial and recreational fishery valued at over \$480 million dollars (Furse and Fox 1994); (2) a rich community of wading birds, migratory waterfowl, and a federally-endangered species, the snail kite (Richardson and Harris 1995; Smith *et al.* 1995); (3) ecotourism and recreation, including bird and wildlife observation, hiking, camping, and boating. These values are dependent to a large extent upon the diverse mosaic of natural vegetation that characterizes the lake's littoral zone (Richardson and Harris 1995; Smith *et al.* 1995), and require that efforts be undertaken to protect this area from significant harm as a result of long-term, low lake stages.

Importance of the Littoral Zone. Persistent low water levels in Lake Okeechobee may cause :

- Loss of critical nesting and foraging habitat for both wading birds and the endangered snail kite (e.g., *Eleocharis* flats within Moonshine Bay). Under extreme low lake stages, a large portion of the lake's snail kite population has been documented to abandon the lake and disperse to other areas of the state (Bennetts *et al.* 1994).
- Extreme low lake stages can result in a significant reduction in littoral zone productivity and loss of fish spawning habitat for a regionally important recreational and commercial fishery valued at \$410 million.
- Stabilized low water levels allow cattails to out compete native species (e.g., bulrush) and expand within the outer fringes of the littoral zone.

The littoral zone marsh occupies approximately 22 percent (98,000 acres) of the total surface area of Lake Okeechobee, and supports a rich community of wetland plants and animals. The spike rush (*Eleocharis*) community represents a large component of the littoral zone and is similar in many respects to those found at pristine sites located within the Everglades. This native sedge and its attached periphyton (algae) community supports a large population of native apple snails, which are the primary food resource for the endangered snail kite. The spike rush community also represents critical spawning and foraging habitat for several important sportfish species such as the largemouth bass, bluegill and longear sunfish.

At the interface between the littoral marsh and the open-water region of the lake, there exists another important community, dominated by giant bulrush (*Scirpus*). This community represents critical habitat for both largemouth bass and black crappie, two of the most important recreational fishes in the lake (Fox *et al.* 1995). In a recent analysis, Furse and Fox (1996) calculated the economic value of this habitat as \$48,828 per acre, for a total value of \$174 million for the entire 3,576 acre habitat. Results of recent drought events (1989-90) showed that during periods of stabilized, low water periods, cattails replaced native bulrush communities within the southern portion of the lake. In general, cattails provide relatively poor habitat for sportfish spawning success due to depressed oxygen levels as compared to bulrush (D. Fox, FGFWFC, personal communication). Loss or reduction of bulrush and spikerush habitat as a result of long-term, low water stages has the potential to impact fish spawning success within the littoral zone. Long-term drawdowns of the lake below 11 ft. NGVD will dry out both spikerush and bulrush communities and therefore, have the potential to cause significant harm to the lake's fish and wildlife resources.

-DRAFT-
Minimum Water Level Criteria

Relationship between Lake Stage and Littoral Zone Flooding and Drying. As lake stages decline, the littoral zone dries out and becomes stressed:

- At 11 ft. NGVD about 94% (92,000 acres) of the littoral zone is exposed as dry land. These conditions provide poor foraging and nesting habitat for fish, waterfowl, wading birds and other aquatic dependent wildlife.

As a result of impoundment of the lake by a dike and its relative shallow lake morphology, Lake Okeechobee typically exhibits a seasonal water level fluctuation of between four or five feet. At elevation 15.0 ft. NGVD, the littoral zone is completely inundated, while at 11 ft. NGVD large areas of the marsh are exposed as dry land (**Figure 10**). At elevation 15.0 ft. NGVD, standing water extends to the toe of the dike, the effective upper boundary for littoral zone plants and animals. At the lower extreme, marsh habitat is almost entirely dried out when water levels fall below 11 ft. NGVD. This is due to the rather steep drop-off that occurs at the interface of the littoral zone and the open water area of the lake (i.e. the marsh community cannot simply expand lakeward from the western shore when water levels become very low). The percentage of the littoral zone exposed as dry land versus lake stage elevation (in feet) are also summarized in **Figure 10**. When water levels drop to 11 ft NGVD, over 94% of the marsh becomes exposed as dry land, offering no habitat value to aquatic species of plants and animals. Littoral zone fish, in particular, are left with little or no nesting habitat, food, or protection from predatory animals. The two critical native plant communities described previously, *Eleocharis* and *Scirpus*, are almost completely dry at this water level. Besides the loss of aquatic habitat, low water conditions also affect the distribution (spread) of exotic plants and increase the occurrence of severe fires which consume peat soils.

Expansion of Introduced Exotics Long-term drying of the littoral zone stimulates growth of undesirable plants such as melaleuca and torpedo grass.

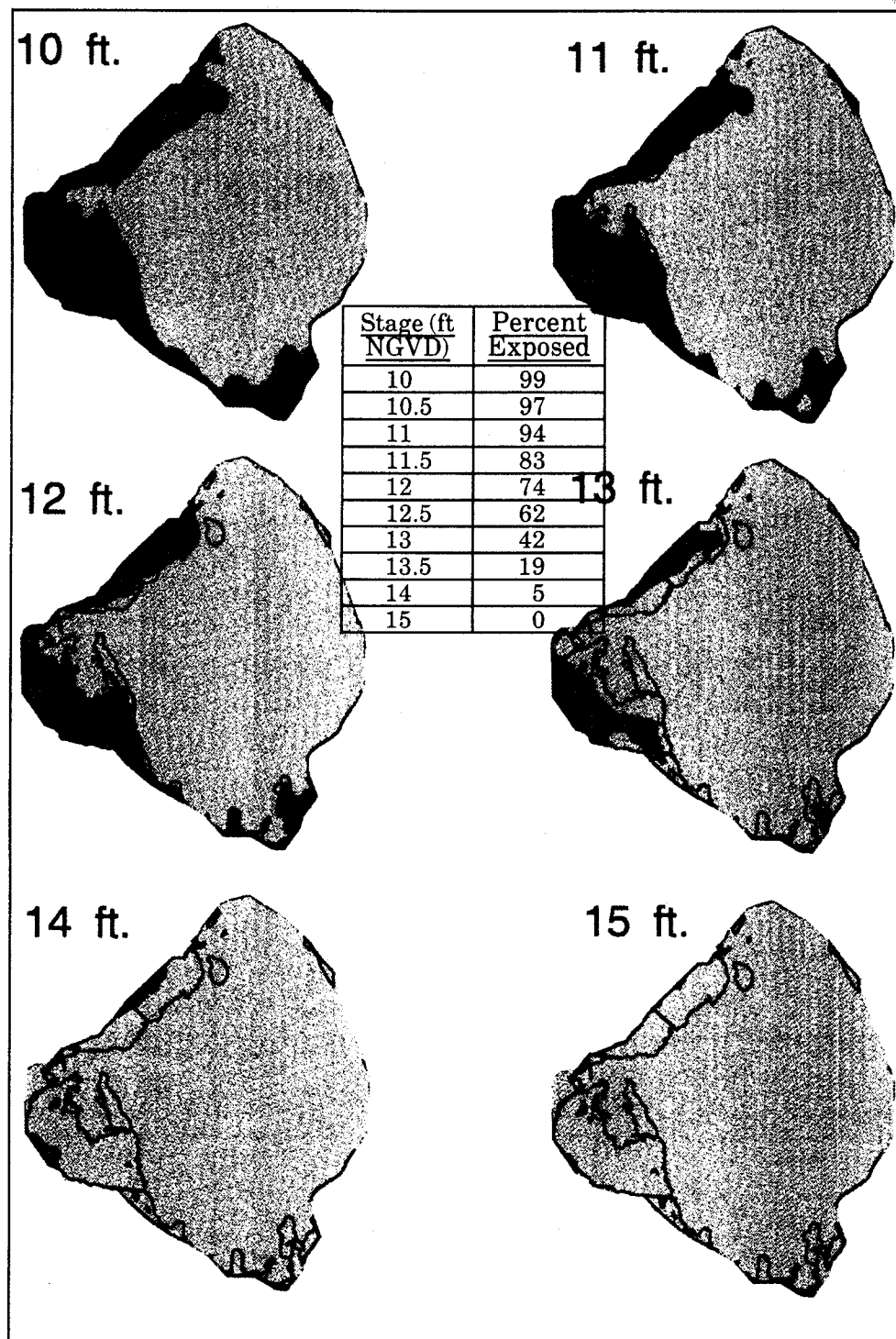
- Upper elevations of the littoral zone become available for invasion by introduced exotics such as melaleuca, torpedo grass (*Panicum repens*) and Brazilian pepper which require expensive mechanical and/or chemical treatment. Once established, woody invaders tend to suppress native species through shading, litter accumulation, and fire tolerance.

In addition to native plants, the littoral zone now contains 15 invasive exotic species, including the melaleuca tree, and torpedo grass (*Panicum repens*). When lake levels fall below 11 ft NGVD, higher elevations of the marsh are exposed as dry land for long periods of time (**Figure 10**). These areas are ideal for the expansion of melaleuca. Expansion of existing torpedo grass communities is also a concern when lake levels fall below 11 ft. NGVD for long periods of time. Torpedo grass has continued to expand in the marsh over the last decade, and now occupies more than 16,000 acres of the littoral zone. Further expansion will likely occur if lake stages are maintained below 11 ft. NGVD for long periods of time. Herbicides, along with controlled fires, are methods that are currently being explored for possible control of torpedo grass.

Increased Frequency of Fire. Reduced water levels also increase the probability of severe fires which impact littoral zone organic soils, vegetation, and wildlife habitat.

- The Lake Okeechobee littoral zone experiences a significant increase in the frequency of severe fires which impact wetland soils, vegetation, and wildlife habitat when water levels fall below 11 ft. NGVD.

-DRAFT-
Minimum Water Level Criteria



Source: Okeechobee Systems Research Division, SFWMD.

Figure 10. Exposed land (dark gray areas) in marsh zones and percentage of total marsh zone exposed for six water level conditions in Lake Okeechobee. At water levels below 10 ft and above 15 ft NGVD, there is 100% and 0% exposure, respectively.

-DRAFT-
Minimum Water Level Criteria

Relationship between Lake Stage and Navigation/Recreation Access.
When lake levels decline below certain levels, boat traffic is impaired:

- Boating access to the lake for fisherman and other recreational boaters becomes limited to maintained channels and boat trails when water levels recede below 11 ft. NGVD. Under these conditions access to large portions of the littoral marsh is limited.

In addition to harming the ecosystem, water levels below 12.56 ft NGVD (minimum authorized channel depth for the Okeechobee Water Way), and in particular those below 11 ft NGVD, significantly impair navigation and recreational uses of Lake Okeechobee and its peripheral waterways (e.g., Taylor Creek, the rim canal, St. Lucie Waterway).

2. Proposed Criteria

The proposed minimum water level criteria for Lake Okeechobee are based on the conclusions derived from a review of available scientific data including (a) review of historical lake stage records; (b) review of the District's Water Shortage Manual and Supply-side Management Plan for Lake Okeechobee; (c) results of a five-year ecological study of the lake (Aumen 1995) and its response to changing water levels; (d) results from a Geographical Information Systems (GIS) model of the lake relative to littoral zone drying versus water depth; (e) documented hydroperiod requirements of native vegetation based on historic records of plant community structure and water level fluctuations in the lake; and (f) navigation and boat access requirements.

In general, under current operating criteria and normal rainfall conditions, water levels in Lake Okeechobee will not fall below 11 ft NGVD. Exceptions occur when there is a regional drought. Under drought conditions, the District implements a Supply Side Management Plan that is designed, in part to protect the water supply in Lake Okeechobee and keep sufficient water in the Lake so that water levels remain above 11 ft NGVD by the end of the dry season (see top of Zone A, **Figure 8**). However, when drought conditions are severe and water levels are predicted to drop below 11 ft by the end of the dry season, the District Governing Board has the authority and responsibility to review water conditions on a monthly basis and determine the amount of water that can and should be released from Lake Okeechobee to protect downstream resources. The establishment of the following MFL criteria does not prevent or preclude the ability of the Governing Board to make such allocation decisions during critical drought periods (see Hall, 1991).

The proposed minimum water level criterion for Lake Okeechobee includes three components -- water depth, return frequency of occurrence, and duration. These three components, in combination, determine whether significant harm will occur to the resource.

- **Minimum Water Depth** is defined as the minimum lake water level that, under normal operational conditions, should not be exceeded in order to protect the water resource.
- **Frequency of Occurrence** is defined as the allowable number of times over the period of record that water levels may recede below the minimum depth without causing significant harm to the lake's water supply, ecology or societal values.

-DRAFT-
Minimum Water Level Criteria

- **Duration** is defined as the amount of time that water levels remain below the minimum level

Based on this information, the following overall water management objectives and minimum water level criteria are proposed for Lake Okeechobee to manage water levels during low rainfall periods:

Minimum Water Depth:

1. *The minimum level for Lake Okeechobee shall be defined as 11 ft NGVD. In addition, water levels should not fall below this level for more than 120 days duration, more often than once every 7 years on average; and not below 10 ft. NGVD more often than once every 40 years on average.*
2. *The establishment of these MFL criteria does not prevent or preclude the ability of the Governing Board to utilize the District's Supply-side management initiatives to make water delivery decisions during critical dry periods.*

B. PROPOSED MFL CRITERIA FOR THE EVERGLADES

Minimum water level limits need to be established within the three Water Conservation Areas, the Holey Land and Rotenberger Wildlife Management Areas, and Everglades National Park. This protection is needed to prevent the occurrence of long-term, low water levels that impact the sustainability of the Everglades system by:

- Reducing wetland aquatic productivity and altering the marsh food chain
- Reducing peat and marl accretion rates, the primary soil building process of the Everglades system.
- Causing oxidation and loss of organic soils that result in lowering of ground level elevations (soil subsidence).
- Increasing the risk of severe fires which cause muck burns, soil subsidence, loss of tree island communities, and alteration of wildlife habitat.
- Reducing the availability of dry season aquatic refugia which sustain Everglades fish, amphibians, aquatic invertebrates and other Everglades wildlife during drought periods.
- Increasing the susceptibility of the marsh to invasion by terrestrial woody vegetation and introduced exotics such as *Melaleuca*.
- Changing the distribution and abundance of Everglades wildlife populations.
- Reducing the amount of surface and groundwater flows that affect the salinity balance of estuaries located in Florida Bay
- Reducing groundwater flows from the Everglades to the east to prevent saltwater intrusion

For the purpose of this study, **significant harm** is defined as a loss of specific water resource functions that take multiple years to recover that result from a change in surface water or ground water hydrology.

-DRAFT-
Minimum Water Level Criteria

1. Technical Relationships that Equate to Significant Harm.

Relationship between Regional Ground Water Levels and Everglades Soils. In its original condition, the Florida Everglades represented the largest single body of organic soils in the world, covering over 3,100 square miles (Stephens, 1984). Formed under anaerobic, water logged conditions, these soils began to subside as wetlands were drained and developed. Subsidence is caused primarily by drainage, biochemical oxidation, compaction, and burning of organic soils. Agricultural development south of Lake Okeechobee has substantially reduced groundwater levels within the Everglades Agricultural Area. Some areas have recorded peat losses of up to 5-6 feet (Stephens, 1984). Significant lowering of ground level elevations has also occurred in the Everglades, primarily along major drainage canals (see **Figure 12**). In the natural system, Everglades peat functioned as a regional freshwater sponge, absorbing rainfall and creating a hydrostatic head higher than what is currently maintained in the system today (Stephens, 1984). Prior to development, groundwater flows to the coast occurred from recharge areas located behind the coastal ridge (Parker *et al.* 1955). Once areas behind the ridge were drained for development, regional groundwater flows to the east coast became governed by groundwater heads maintained in the Everglades. These flows move primarily eastward from the Everglades to the Lower East Coast via groundwater or the regional canal network and help stabilize the freshwater/saltwater interface (Fish and Stewart, 1991). The continued loss of peat resources in the Everglades and associated loss of freshwater head may further reduce ground water flows to the east and thus increase the threat of saltwater intrusion during drought periods. Saltwater intrusion into coastal wellfields has been the chief threat to South Florida's water supply since drainage activities began in the early 1900's (Stephens, 1984). Providing adequate minimum water levels in the Everglades during low rainfall years is important, to preserve peat resources and future water supplies.

Everglades Water Levels and Soil-Plant Community Relationships.

Peat Formation and Soil Loss in the Everglades. Peat is formed in the Everglades from remains of either slough vegetation (Loxahatchee peat), or sawgrass (Everglades peat) communities. Within the range of water depths that favor peat formation, deep water, (up to two feet deep) long-hydroperiod conditions tend to favor the formation of Loxahatchee peat, while shallower water depths and shorter hydroperiods favor the production of Everglades peat (Gleason and Stone, 1994; Tropical BioIndustries Inc., 1990). Based on soil surveys conducted by Jones *et al.* (1948), Loxahatchee peat was found primarily in WCA-1, the northern portion of WCA-2A, western WCA-3A, WCA-3B, and the Shark River Slough region of Everglades National Park. Everglades peat was found primarily in southwestern WCA-2A, northeastern WCA-3A, northern WCA-3A and within the Holey Land and Rotenberger Wildlife Management Areas. **Figure 13** (adapted from Jones, *et al.*, 1948) shows the spatial distribution of the major hydric soil types (Loxahatchee peat, Everglades peat, Perrine marl, Ochopee marl and Rockland marl) found within the Everglades during the mid-1900's in relationship to the location of present day water management gages.

Formation of peat soils requires near-permanently flooded or saturated soils with water depths averaging 1.5 to 2.0 ft deep and a hydroperiod of at least 9-10 months duration. Dry season water table recessions should not exceed more than one foot below ground for more than 30 days during a dry year. Under these conditions, surface peats remain saturated due to capillary action, pulling moisture from the underlying groundwater table to provide aquatic plants and burrowing organisms with enough soil moisture to survive dry periods. Although water levels may

-DRAFT-
Minimum Water Level Criteria

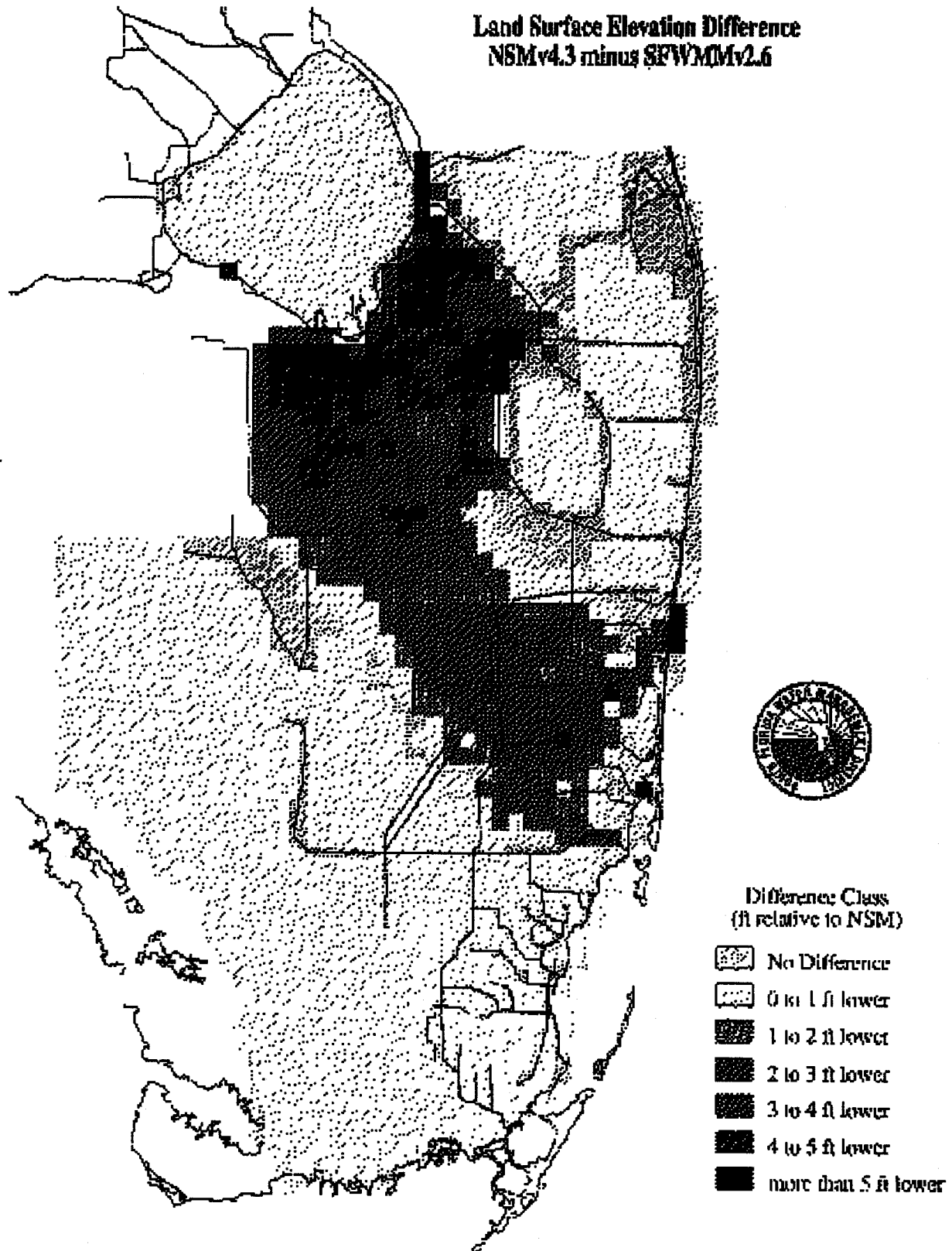
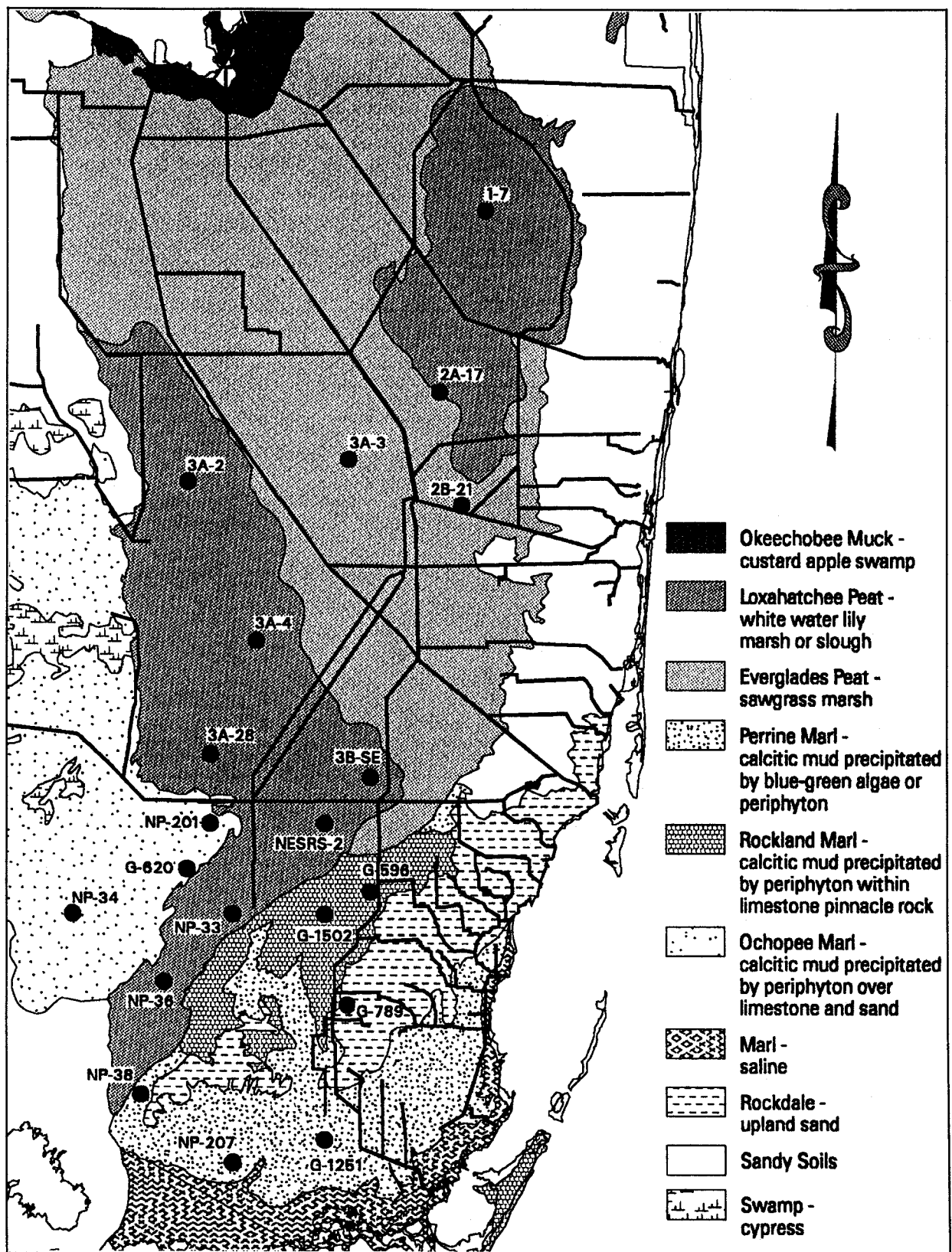


Figure 12. Soil Subsidence in the Everglades Region of South Florida



Source: SFWMD, based on Jones et al., 1948

Figure 13. Spatial distribution of the major hydric soil types within the EPA in relationship to the key water management gages.

**-DRAFT-
Minimum Water Level Criteria**

occasionally drop more than one foot or more below ground during a major dry period, slough aquatic plants quickly recover from buried tubers, seeds and other resting plant structures (Tropical BioIndustries Inc. 1990).

Peat accretion (the slow accumulation of peat over time) is a fundamental process that is needed to maintain a functioning wetland system. Average peat accretion rates in the Everglades range from 0.04-0.06 inches/year (Davis 1946; McDowell *et al.* 1969) to 0.11-0.13 inches/year for WCA-3A and WCA-2A, respectively (Richardson and Craft 1990). There is a large body of evidence indicating that construction and operation of the Central and Southern Florida Flood Control Project has altered the hydrologic regime of historic soil-plant communities. In many areas of the Everglades, reduced water levels and shortened hydroperiods have reversed the process of peat accretion resulting in the oxidation of organic soils and lowering of ground level elevations. This process is called soil subsidence. Numerous studies have reported the results of extreme drought within the Everglades system and its effects on organic soils, plant communities, and wildlife (Loveless 1959; Craighead 1971; Schortemeyer 1980; Wade *et al.* 1980; Zaffke 1983; Alexander and Crook 1984; Hoffman *et al.* 1994; and Gunderson and Snyder, 1994). For example, during the 1981 drought, water levels in northern WCA-3A receded 2-3 feet below ground for five months. Wildfires have burned the roots out from under tree islands and exposed bedrock, resulting in peat losses of more than one foot over large areas of WCA-3A (Loveless 1959; Schortemeyer 1980; Zaffke 1983).

Results of a computer analysis are shown in **Figure 12**, indicating the differences in ground level elevations between pre-drainage conditions, as simulated by the Natural Systems Model (NSM), and present day conditions, as simulated by the South Florida Water Management Model (SFWMM). The greatest amount of soil subsidence, more than five feet in some areas, has occurred in the highly managed Everglades Agricultural Area (EAA), located south of Lake Okeechobee. Major losses within the WCA's occur primarily near the "subsidence valleys" that are located along major canals, the northern portion of WCA-3A, the southwest portion of WCA-2A, and northern WCA-3B (**Figure 12**). These data correlate well with recorded peat losses within the EAA (Stephens, 1984) and northern WCA-3A (Schortemeyer 1980; Zaffke 1983), where severe peat fires have impacted wetland vegetation and wildlife communities. The largest peat losses occurred on tree islands resulting in the permanent destruction of wildlife habitat. Hoffman *et al.* (1994) also reported the effect of fires and extensive peat losses in WCA-3A resulting from major drought events. Loss of these soils and their associated parent plant communities as a result of low water levels and reduced hydroperiods are a concern for several reasons:

- Under typical conditions, it takes from 200-300 years to produce one foot of peat soil. Best available data indicate that in many areas of the Everglades, peat soils are being lost from the system faster than they accumulate, thus the system is not sustainable under the current hydrologic regime.
- Increased frequency of severe fires, which consume peat and damage Everglades plant communities and associated wildlife habitat, can result in ecological impacts that last from 3 to 10 decades (DeAngelis, 1994). These long-term changes represent significant harm to the Everglades ecosystem.
- Continued subsidence of organic soils and the associated loss of freshwater head will over time, reduce the overall amount of water available in the regional system for protection of coastal aquifer resources against saltwater intrusion, and for maintenance of downstream estuarine communities within Florida Bay.

-DRAFT-
Minimum Water Level Criteria

Fire History. Incidence of severe fires in the Everglades in recent history has been qualitatively summarized and, where data were available, linked to drought periods

-DRAFT-
Minimum Water Level Criteria

- 2) In the second simulation, coastal canals were not maintained for water supply purposes during drought years. District operations did not attempt to maintain dry season water levels in the coastal canals.

Results of the first scenario were compared with results of the second canal scenario at 20 key monitoring locations. **Table A-3, Appendix A** provides a summary of these results. When the coastal canals were not maintained during dry periods, there was an increase in the number of days that coastal canal water levels fell below 1 foot NGVD. The threat of salt water intrusion significantly increased. When coastal water levels were below 1 ft NGVD for longer periods of time, a reverse gradient developed as coastal aquifer water levels fell near or below sea level. Denser salt water from the ocean could then move inland into the freshwater portions of the aquifer. Results of these simulations indicate, that for most areas, coastal water levels appear to be highly influenced by water levels in the regional canal network. Water levels in the coastal canals largely govern the expected inland extent of the saline interface. Managing coastal canals at appropriate water levels during drought periods is a viable option for stabilizing the salt water interface and preventing further inland migration of the saltwater front. **Appendix A** provides a more detailed summary of the results of these simulations for northern, central and southern Palm Beach County, Broward and Dade counties

Evaluation of Coastal Canal Stages Since it appears that the coastal canals help control water levels along the Lower East Coast of Florida, an evaluation of canal stage levels is necessary. Upstream canal water levels from each of the primary canals were obtained from historical records. Daily stages, where available, were obtained from each structure for the period from 1980 to the present. Structures in South Dade County were not included in the evaluation due to the uncertainty associated with minimum flows for Biscayne Bay and Florida Bay. Hydrographs and stage duration plots for each structure were developed for the same time frame and are provided in **Appendix A**.

The mean stage (50th percentile) and the 84th percentile stage for each structure are presented in **Table 4**. The 84th percentile statistically represents one standard deviation from the mean. In addition, the estimated level necessary to impede inland migration of the salt water interface was calculated for each structure based on aquifer thickness and the Ghyben-Herzberg relationship. Also included in **Table 4** are the canal maintenance levels used by the District, as simulated in the South Florida Water Management Model (SFWMM). The levels used in the SFWMM were determined from an evaluation of historical canal stages to determine the average water level that was managed at each structure during times when water supply deliveries were made. When simulated canal stages fall below this level, the SFWMM simulates importation of water into the canal from the Water Conservation Areas or Lake Okeechobee.

Results of these model simulations indicate that coastal canal levels are managed at or above the Ghyben-Herzberg level north of Fort Lauderdale, and below the Ghyben-Herzberg level south of Fort Lauderdale. This is due primarily to the difference in the topography of these two areas. With the exception of the Coastal Ridge, ground level elevations decrease from 15 - 20 ft. NGVD in Palm Beach County, to less than 5 ft. NGVD in parts of southwestern Broward and Dade County. As a result, local canal levels must be maintained at lower elevations to prevent urban and agricultural flooding.

**-DRAFT-
Minimum Water Level Criteria**

Table 4. Stages at key water management structures located along Florida's lower East Coast (stages are in feet NGVD)

Water Management Structure	Mean or 50th percentile Stage (ft NGVD)	84th Percentile ¹ (ft NGVD)	Ghyben-Herzberg Relationship	Canal Stages Maintained by SFWMD ² (ft NGVD)
G-54	3.68	3.28	4.00	3.50
G-56	7.43	6.75	5.00	7.00
S-155	8.12	7.74	5.00	7.80
S-174	4.25	3.49	3.10	4.00
S-177	3.21	2.72	1.25	3.00
S-22	2.86	2.04	2.70	2.20
S-25B	2.55	1.95	3.25	2.20
S-26	2.55	2.07	3.25	2.00
S-37B	6.82	6.60	4.50	6.50
S-40	8.39	7.59	5.00	7.80
S-41	8.23	7.72	5.00	7.80
S-29	2.16	1.90	4.00	1.80
S-36	4.43	4.15	5.00	3.80

¹ = 84th percentile represents one standard deviation from the mean

² = Canal stages maintained by the District at specific canals as simulated in the South Florida Water Management Model (SFWMM)

canal water levels and movement of the salt water interface, several important factors were observed:

1. The Ghyben-Herzberg relationship is conservative for South Florida conditions. That is, if water levels are maintained at or above the theoretical positions dictated by this equation, the threat of salt water intrusion is minimized.
2. Water levels along coastal Dade, Broward and Palm Beach counties are largely controlled by the District's primary canal system. Regionally, these canal systems control the position of the salt water interface.
3. Water levels in these primary canals are generally managed above the Ghyben-Herzberg levels north of Fort Lauderdale and below the predicted level south of Fort Lauderdale. The ability to manage higher canal levels south of Fort Lauderdale is limited by existing development and topography.
4. Results of these simulations indicate that on a regional scale, the position of the salt water interface can be regulated by the management of water levels in the District's canal system. Localized intrusion problems still need to be investigated and handled through detailed investigations and permitting.

The final approach used to investigate potential movement of the saline interface focused on model simulations of three proposed minimum canal water level scenarios using the SWICHA model developed by Andersen *et al.* (1986). These three scenarios included: (a) setting the minimum canal level based on the mean stage or 50th percentile level; (b) setting the minimum canal level based on the 84th percentile; and (c) setting the minimum canal level based on the Ghyben-Herzberg relationship.

**-DRAFT-
Minimum Water Level Criteria**

The results from this analysis were used in determining minimum flows and levels at each of the District's primary structures. The minimum flows and levels were based on minimizing the threat of salt water intrusion without adversely affecting flood control. More detailed discussion of these simulations and result are presented in **Appendix A**.

2. Proposed MFL Criteria.

Selection of Minimum Canal Levels to Protect the Biscayne Aquifer. Groundwater levels within the Biscayne aquifer are controlled by local rainfall and by canals and structures that are regionally operated by the SFWMD. The aquifer system becomes more rainfall driven and less canal dependent as the distance from the canals increases. However from the data presented in this report, it appears that canal water levels play a major role in determining the elevation of freshwater levels in the Biscayne aquifer throughout most of South Florida. Because of this relationship, minimum levels are proposed for the District' primary coastal canals to protect the Biscayne aquifer against further saltwater intrusion. The proposed criteria consist of two components, (a) minimum canal water depth and (b) duration of the event. These terms are defined as follows:

- Minimum Canal Depth. The minimum water level in a canal, which, if managed for a specific period of time, is sufficient to protect the coastal aquifer from the threat of saltwater intrusion (i.e. significant harm) during a period of deficient rainfall.
- Duration. The estimated period of time that canal water levels may remain below the minimum level without causing significant harm to coastal groundwater resources.

Minimum canal water levels are proposed for eleven primary control structures located along the Lower East Coast of Florida. Key requirements for selecting these structures were that they: (a) must be connected to the regional system, and (b) have a sufficient canal conveyance capacity to receive water from outside of their drainage basins. The values proposed in **Table 5** represent minimum levels necessary to protect the Biscayne aquifer and stabilize the saline interface.

In general terms, these minimum canal levels were derived from stage duration curves using values between the historical mean (50th percentile) and the 84th percentile for each canal. Details of these analyses are presented in **Appendix A**.

On a regional scale, the SFWMD will manage canal levels at or above the minimum levels specified in **Table 5** for each of the eleven principle water control structures located along the southeast coast of Florida. Water levels will be managed at these levels when sufficient water is available in the regional system. These water levels will be allowed to go below the specified level during times when water is not available to maintain the canal system or when significant rainfall has occurred that requires opening of the control structures to prevent upstream flooding. Water levels within the canals can fall below the proposed minimum canal level for a period of no more than 180 days per year. These canal levels however, need to recover sufficiently so that on an average basis, water levels will be managed at or above the specified minimum canal levels shown in **Table 5**. Actual operation of the C&SF Project canal system will be addressed in detail in the minimum flows and levels recovery and prevention strategy section of the Lower East Coast Regional Water Supply Plan.

In areas that are located away from the principal water control structures, the SFWMD will continue to regulate users to ensure that additional movement of the saline interface does not occur above or below levels expected for a 1 in 10 year

-DRAFT-
Minimum Water Level Criteria

Table 5. Recommended Minimum Canal Levels and Duration Criteria for the Biscayne Aquifer.

Major Canal/ Water Management Structure	Proposed Minimum Canal Level* (feet NGVD)
C-51/S-155	7.75
C-51/S-41	7.75
C-51/S-40	7.75
Hillsboro/G-56	6.75
C-14/S-37B	6.50
C-13/S-36	4.00
North New River/G-54	3.50
C-9/S-29	2.00
C-6/S-26	2.50
C-4/S-25B	2.50
C-4/S-22	2.50

* = Duration Criteria: Water levels within the above canals may fall below the proposed minimum canal level for a period of no more than 180 days per year.

drought event. The District will regulate consumptive uses to restrict the net annual inland movement of the saline interface. Uses will be evaluated, on individual and cumulative bases, to ensure that no movement of the salt water interface occurs.

To prevent significant harm due to movement of the salt water interface, the SFWMD will continue to manage water levels at or above proposed minimum levels in canals located upstream from eleven principle water control structures located along the Lower East Coast, except during periods when flooding may occur.

Proposed MFL criteria for protection of the Biscayne aquifer are:

*Minimum Level: Water levels at the eleven specified water control structures shown in **Table 5** shall not fall below the proposed minimum level for more than 180 days in a 365 day period excluding periods of flood releases.*

Surface and Ground Water Flows in South Dade County, Florida. The situation in South Dade County is highly complex. Historically, groundwater flowed eastward and discharged into Biscayne Bay, while surface waters flowed southward towards the eastern Everglades, eventually reaching Florida Bay, Barnes Sound and Card Sound. With subsequent draining of South Dade County, both surface and ground water flows to Biscayne Bay were significantly altered (Buchanan and Klein, 1976). Ground water and surface water flows toward northeastern Florida Bay also appear to have been altered, although additional work is needed to determine the extent. In addition to drainage, salinity regimes and circulation patterns in Florida Bay and Barnes Sound appear to have been modified by the construction of Flagler's Florida Keys Railroad (McIvor, *et al.*, 1994).

A secondary problem in southern Dade County is the relatively thin soil. Due to these shallow soils, canals are cut into the oolitic and bryozoan facies of the Miami Limestone and have penetrated into the Fort Thompson Formation in some areas. As a result, these canals are directly connected to some of the most permeable sections of

***-DRAFT-
Minimum Water Level Criteria***

the Biscayne aquifer. It is therefore difficult to maintain canal stages for extended periods of time without using a significant volume of water from regional storage.

For these reasons, it is beyond the scope of this report to address minimum flows and levels for Florida Bay, Biscayne Bay, Card Sound and Barnes Sound. However, it is reasonable to assume that by setting a minimum level for the Biscayne aquifer in South Dade County, based solely on maintaining the existing position of the saline interface, critical ground water flows moving east towards Biscayne Bay and south towards Florida Bay may be further restricted. The result may be an unsatisfactory minimum flow and level for ground and surface water flows to other downstream estuaries. Therefore, it is recommended that the MFL for the Biscayne aquifer in southern Dade County be developed concurrently with the development of MFLs for Biscayne Bay, Florida Bay, Card Sound and Barnes Sound.

-DRAFT-
Minimum Water Level Criteria

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS AND RECOMMENDATIONS FOR SPECIFIC RESOURCES

- For the purpose of this study, **significant harm** is defined as a loss of specific water resource functions that take multiple years to recover, that result from a change in surface water or ground water hydrology.
- Structural changes or alterations that have occurred within the region, the effects these changes have had, and the constraints they impose on the water resources of South Florida were considered as part of the process for developing MFL criteria for Lake Okeechobee, the Everglades, and the Biscayne aquifer.

1. Lake Okeechobee.

- Construction and operation of the C&SF Project has reduced historical lake levels to prevent hurricane flooding of lakeside communities and provide water supply to downstream agricultural and urban interests. Construction of levees around the perimeter of the lake has dramatically reduced the size of the lake's littoral zone and moved littoral zone habitats to new locations.
- Best available scientific information indicates that frequent or prolonged drawdowns of Lake Okeechobee below 11 ft. NGVD will cause significant harm to this water resource by reducing the District's ability to reserve water within the regional system. This reserve supply of water is needed within Lake Okeechobee to meet urban, agricultural, and environmental water needs during periods of below normal rainfall.
- Minimum water level limits were established in Lake Okeechobee in order to:
 - * Reserve water in the lake during wet periods that can later be discharged during dry periods to maintain a freshwater head in coastal canals. Water levels must be maintained in these canals to meet local water supply needs and prevent significant harm from occurring to the coastal aquifer due to saltwater intrusion.
 - * Provide supplemental water supplies for the Everglades Agricultural Area (EAA), the Caloosahatchee and St. Lucie basins during low rainfall periods to reduce potential economic losses due to crop failure.
 - * Prevent significant harm from occurring to the ecological resources of Lake Okeechobee including its littoral zone, sport and commercial fisheries and resident endangered species populations.
 - * Prevent the occurrence of long-term low water stages that restrict navigation and recreational use of the lake by the public.
 - * Provide water supply for Everglades National Park
- As part of the Central and Southern Florida Project, Lake Okeechobee plays a critical role as a source of freshwater for maintaining coastal groundwater levels to prevent saltwater intrusion of the Biscayne aquifer.

-DRAFT-
Minimum Water Level Criteria

- Present operational criteria require that when lake levels fall below 11 ft. NGVD, water shortage restrictions are imposed along Florida's Lower East Coast
- Best available scientific information indicates that frequent or prolonged drawdowns of Lake Okeechobee below 11 ft. NGVD will cause significant harm by reducing the District's ability to reserve enough water within the lake to maintain coastal canal levels and prevent saltwater intrusion during dry periods.
- The littoral zone comprises 22% of the lake surface and provides critical habitat for a wide variety of aquatic plant and animal species. This includes nursery and feeding areas for a nationally renowned sports fishery and habitat for several endangered species. Migratory birds and waterfowl also use the littoral zone as a resting area along the Atlantic flyway.
- Best available scientific information indicates that frequent or prolonged drawdowns of the lake below 11 ft NGVD will cause significant harm to the lake's littoral zone. The following impacts are expected to occur if the minimum criteria are exceeded:
 - * At 11 ft. NGVD about 94% (92,000 acres) of the littoral zone is exposed as dry land. These conditions provide poor foraging and nesting habitat for fish, waterfowl, wading birds and the endangered snail kite.
 - * Extreme low lake stages can result in a significant reduction in littoral zone productivity and loss of fish spawning habitat for a regionally important recreational and commercial fishery valued at \$410 million.
 - * Stabilized low water levels allow cattails to out compete other native species (e.g., bulrush) and expand within the outer fringes of the littoral zone.
 - * Important native plant communities are replaced by torpedo grass and *Melaleuca*. This process has already occurred in upland regions of the marsh, and now threatens large regions of the marsh now dominated by *Eleocharis*.
 - * Increased risk of severe, large-scale fires that consume peat and impact wetland vegetation and wildlife.
 - * Reduced ability to provide supplemental water to Everglades National Park when the current plan requires deliveries.
- Boating access to the lake for fisherman and other recreational boaters becomes limited to maintained channels and boat trails when water levels recede below 11 ft. NGVD. Under these conditions, access to large portions of the littoral marsh are limited. Navigation and recreational access to the lake are impaired.
- Proposed MFL criteria for Lake Okeechobee are based on (a) a review of historical lake stage records; (b) Review of the District's Water Shortage Manual and Supply-side Management Plan for Lake Okeechobee; (c) results of a five-year ecological study of the lake; (d) Geographical Information Systems (GIS) model of the lake; (e) hydroperiod requirements of native wetland vegetation based on historic records of plant community structure and water level fluctuations in the lake; and (f) navigation and boat access requirements.

-DRAFT-
Minimum Water Level Criteria

Minimum Level:

- a. *The minimum level for Lake Okeechobee shall be defined 11 ft NGVD. Water levels should not fall below 11 ft. NGVD for more than 120 days duration, more often than once every 7 years on average; and not below 10 ft. NGVD more often than once every 40 years on average.*
- b. *The establishment of these MFL criteria does not prevent or preclude the ability of the Governing Board to utilize the District's Supply-side management initiatives to make water delivery decisions during critical dry periods.*

2. The Everglades

Minimum water level limits need to be established within the Everglades (the Water Conservation Areas, Holey Land and Rotenberger Wildlife Management Areas and Everglades National Park) to prevent the occurrence of long-term, low water levels that impact the sustainability of the Everglades system by:

- Reducing wetland aquatic productivity and altering the marsh food chain
- Reducing peat and marl accretion rates, which are the result of the primary soil building processes within the Everglades system.
- Causing oxidation and loss of organic soils that result in lowering of ground level elevations (soil subsidence).
- Increasing the risk of severe fires that cause muck burns, soil subsidence, loss of tree island communities, and alteration of wildlife habitat.
- Reducing the availability of dry season aquatic refugia which sustain Everglades fish, amphibians, aquatic invertebrates and other Everglades wildlife during drought periods.
- Increasing the susceptibility of the marsh to invasion by terrestrial woody vegetation and introduced exotics such as *Melaleuca*.
- Changing the distribution and abundance of Everglades wildlife populations.
- Reducing the amount of surface and groundwater flows that affect the salinity balance of estuaries located in Florida Bay.
- Reducing groundwater flows from the Everglades to the east to prevent saltwater intrusion.

Minimum criteria developed for the Everglades were designed to protect Everglades wetlands by preventing the loss of hydric soils. Hydric soils (freshwater peat and marl) were selected as the parameter of choice because:

- Peat and marl are the primary soils that characterize the Everglades. More than 90% of the remaining Everglades are comprised of these soils.
- Peat and marl soils sustain all of the major wetland plant associations (sawgrass marshes, sloughs, wet prairies and tree islands) and animal communities that characterize the Everglades.
- Review of the literature indicates that both of these soil types are reliable indicators of past hydrological/biological conditions within the Everglades.

-DRAFT-
Minimum Water Level Criteria

- Sufficient data concerning historical and present-day soil conditions exist that can be used as a reasonable basis for setting initial minimum water level criteria for the Everglades (Tropical BioIndustries Inc. 1990)

Development of the proposed MFL criteria were based on an extensive review of the literature, comparison of the proposed criteria to historical water levels and fire histories within the Everglades, and comparison to the Natural System Model (version 4.5) as an estimate of minimum pre-drainage water levels.

Proposed MFL criteria are based on the rationale that groundwater drawdowns and durations greater than those recommended have the potential to cause harm to hydric soils and associated wetland vegetation and wildlife. The following impacts can be expected to occur if the proposed criteria are exceeded:

- Reversal of the natural process of peat accretion and an increase in the rate of soil oxidation and soil subsidence (lowering of ground level elevations), which reduce the long-term sustainability of the Everglades ecosystem.
- Reduced wetland aquatic productivity, disruption of food chains, loss of dry season aquatic refugia, shifts in wetland vegetation from wet-adapted species to those more tolerant of drier conditions, and invasion by exotic species such as *Melaleuca*.
- Increased frequency of severe fires that consume peat, damage tree islands, expose bedrock, lower ground level elevations and destroy wildlife habitat that supports rare, threatened or endangered species.
- Continued loss of peat resources and associated freshwater head within the EPA has the potential to reduce the water storage capacity of the regional ecosystem and increase the threat of saltwater intrusion during droughts.

Proposed minimum criteria for peat-forming areas of the Everglades:

- *Water levels within wetlands overlying organic peat soils within the WCAs, Rotenberger/Holey Land WMAs, and Shark River Slough (ENP) should not fall 1.0 ft or more below ground level for more than 30 days duration, at return frequencies that are not less than those shown in Tables 3 and 4 of this report.*

Proposed minimum water levels for marl-forming wetlands located within Everglades National Park are:

- *Water levels within marl-forming wetlands that are located east and west of Shark River Slough, the Rocky Glades, Taylor Slough and the C-111 basin within Everglades National Park should not fall below 1.5 ft. below ground level for more than 90 days, at a return frequency not more frequently than once in 5 years (Tables 3 and 4).*

3. Coastal Biscayne Aquifer.

Minimum levels proposed for the Biscayne Aquifer were developed to minimize further saltwater intrusion within the coastal aquifer.

- The Biscayne aquifer represents the primary source of water supply for urban and agricultural users along Florida's Lower East Coast. The Biscayne aquifer also

***-DRAFT-
Minimum Water Level Criteria***

provides base flow to important estuaries such as Biscayne Bay and Florida Bay during low rainfall years.

- The groundwater hydrology of South Florida has been permanently altered by urban and agricultural development and construction of the Central and Southern Florida Project. Canal construction has drained the Biscayne aquifer, resulting in inland migration of the saline interface. Construction of the coastal canal structures has helped to stabilize the saline interface, although some areas still show evidence of continued saltwater intrusion.
- Water levels within the Biscayne aquifer are influenced by local rainfall and the operation of District water management structures along major canals. These regionally maintained canals directly influence groundwater levels within the Biscayne aquifer. Because of this relationship, minimum levels are proposed for the Biscayne aquifer by controlling coastal canal stages on a regional scale.

Based on best available information, data analyses and modeling results presented in this report, District staff recommends the following regarding development of minimum flows and levels for the Biscayne aquifer:

- Protection of the Biscayne aquifer against salt water intrusion represents a District priority for resource protection.
- Manage minimum freshwater elevations within the Biscayne aquifer in a manner that will protect the existing orientation of the freshwater/saltwater interface on a regional and local scale.
- Address maintenance of existing freshwater elevations on a regional scale by the operation of the Central and Southern Florida Project and on a local scale through the regulation of consumptive uses.
- On a regional scale, maintain minimum canal levels as presented in **Table 5** of this report for each of the existing 11 primary salinity control structures located along the Lower East Coast.
- Regulate local consumptive uses and drainage systems, within the District's jurisdiction, in a manner that will restrict the net annual inland movement of the saltwater/freshwater interface.
- Develop a detailed groundwater model that can adequately simulate movement of the saline interface under transient conditions; use this model to refine the levels and duration component proposed in **Table 5**, which are intended to provide interim minimum levels for the Biscayne aquifer.
- Develop a comprehensive monitoring program to integrate the chloride monitoring network and the canal stage network. If water levels in the regional canal network remain below the minimum level specified in **Table 5** for extended periods of time, an investigation will need to be undertaken to determine the cause of the depressed canal levels and associated remedies.
- Continue water shortage restrictions driven by existing SFWMD water shortage policy. (Canal stages should be used as an indicator of potential problems).

-DRAFT-
Minimum Water Level Criteria

- The Lower East Coast Regional Water Supply Plan will investigate the need to maintain water levels in additional canals, or modify the stages recommended in Table 5, as a result of proposed changes in the C&SF Project Restudy.
- To prevent significant harm due to movement of the salt water interface, the SFWMD will continue to manage water levels at or above proposed minimum levels in canals located upstream from eleven principle water control structures located along the Lower East Coast, except during periods when flooding may occur.
- Proposed MFL criteria for protection of the Biscayne aquifer are:
Minimum Level: Water levels at the eleven specified water control structures shown in Table 5 of this report shall not fall below the proposed minimum level for more than 180 days in a 365 day period excluding periods of flood releases.
- Minimum levels for the Biscayne aquifer in southeastern Dade County are not recommended at this time. The methodology used in this report assumes a goal of stabilizing the saline interface and does not account for freshwater flows that are moving towards coastal water bodies. The District is presently undertaking several studies to assess the groundwater flow needs of both Biscayne Bay and Florida Bay. Anticipated completion dates of these reports are 1999. It is recommended that minimum flows for the Biscayne aquifer in southeastern Dade County be developed when minimum flows are developed for Biscayne Bay and Florida Bay to protect these two coastal water bodies.

B. GENERAL RECOMMENDATIONS

The District should adopt minimum flows and levels for the Biscayne aquifer, Everglades Protection Area, and Lake Okeechobee. To accomplish this task, the revised minimum flows and levels document developed as a part of the Lower East Coast Regional Water Supply Plan should be scientifically peer reviewed to ensure the technical soundness of the data, conclusions and proposed criteria. Modifications that result from the peer review should be incorporated into the criteria, and rulemaking should be initiated. The criteria and information developed as part of this minimum flows and levels document will be incorporated into the draft rule. This process will provide for full participation by interested and affected parties.

-DRAFT-
Minimum Water Level Criteria

V. LITERATURE CITED

- Alexander, T.R. and A.G. Crook. 1973. Recent and Long Term Vegetation Changes and Patterns in South Florida, Part I, Preliminary Report, South Florida Ecological Study, Appendix G, University of Miami, Coral Gables, FL.
- Alexander, T. R. and A.G. Crook. 1984. Recent vegetation changes in South Florida. In: Gleason (ed.) *Environments of South Florida: Past and Present*. Miami Geological Society, Miami FL.
- Andersen, P.F., White, H.O., Mercer, J.W., and Huyakorn, P.S., 1986. Numerical modeling of groundwater flow and saltwater transport in the vicinity of Hallandale, Florida. *Geotrans*, Herdon, Va, 176 p.
- Andersen, P.F., Mercer, J.W., and White, J.W., 1988. Numerical modeling of salt-water intrusion at Hallandale, Florida. *Groundwater*, V 26 (5), p.619-630.
- Aumen, N.G. 1995. History of human-related impacts to Lake Okeechobee, Florida (U.S.A.), related research, and lake management issues. *Archiv fur Hydrobiologie*, Advances in Limnology, 45, 1-30.
- Aumen, N.G. and S. Gray. 1995. Research synthesis and management recommendations from a five-year, ecosystem-level study of Lake Okeechobee, Florida (USA). *Archiv fur Hydrobiologie*, Advances in Limnology, 45, 343-356.
- Aumen, N.G. and R.G. Wetzel. 1995. Ecological Studies on the Littoral and Pelagic Systems of Lake Okeechobee, Florida (USA). *Archiv fur Hydrobiologie*, Advances in Limnology, Volume 45.
- Bancroft, G.T. 1993. Florida Bay-An endangered North American jewel. *The Florida Naturalist*, Spring 1993.
- Bancroft, G.T., A.M. Strong, R.J. Sawicki, W. Hoffman, S.D. Jewell 1994. Relationships among wading bird foraging patterns, colony locations, and hydrology in the Everglades. In: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie Press, Delray Beach, FL.
- Bear, J., 1972. Dynamics of fluids in porous media. American Elsevier, New York, NY, 764 p.
- Bell, F.W. 1987. The Economic Impact and Valuation of the Recreational and Commercial Fishing Industries of Lake Okeechobee, Florida. Technical Report, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.
- Bennetts, R.E., M.W. Collopy, and J.A. Rodgers, Jr. 1994. The snail kite in the Florida Everglades: A food specialist in a changing environment. In: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL.
- Bodle, M. J., A.P. Ferriter and D.D. Thayer, 1994. The biology, distribution and ecological consequences of *Melaleuca quinquenervia* in the Everglades. In: Davis, S.M. and J.C. Ogden (Eds). *Everglades: The Ecosystem and Its Restoration*. St. Lucie Press, Delray Beach, FL.

-DRAFT-
Minimum Water Level Criteria

- Boesch, D.F., N.E. Armstrong, C.F. D'Elia, N.G. Maynard, H.W. Paerl, and S.L. Williams. 1993. Deterioration of the Florida Bay ecosystem: an evaluation of the scientific evidence. Report to the Interagency Working Group on Florida Bay, Nat. Fish and Wildlife Foundation, Nat. Park Service, So. Fla. Water Management District, Sept. 15, 1993. 27 pp.
- Brooks, H.D., 1974. Lake Okeechobee. In: Gleason (ed.) *Environments of South Florida: Past and Present, Memoir 2*, Miami Geological Society, Miami FL. pp. 256-286.
- Browder, J.A. 1981. Perspective on the ecological causes and effects of the variable algal component of southern Everglades periphyton. South Florida Research Center Report T-643, National Park Service, Everglades National Park, Homestead, FL.
- Buchanan, T.J. and H. Klein, 1976. Effects of Water Management on Fresh Water Discharge to Biscayne Bay. In: Biscayne Bay, Past/Present/Future. Proc. Biscayne Bay Symposium I, April 2-3, 1976. University of Miami (Florida), Sea Grant Special Report No. 5. pp 271-277.
- Cornwell, G. and E.C. Hutchinson 1974. An ecological analysis of an Everglades Township in Southwest Palm Beach County, Florida, Ecoimpact Inc., Gainesville, FL.
- Chamberlain, R.H., D.E. Haunert, P.H. Doering, K. Haunert, and J. Otero 1995. Preliminary estimate of optimum freshwater inflow to the Caloosahatchee Estuary, Florida. South Florida Water Management District, West Palm Beach, FL.
- Cohen, A.D. and W. Spackman, 1977. Phytogenic organic sediments and sedimentary environments in the Everglades-mangrove complex. Part II. The origin, description and classification of the peats of southern Florida. *Palaeontographica*, 162 (Abt.B):71-114.
- Costanza, 1975. The spatial distribution of land use systems, incoming energy and energy use in South Florida from 1900 to 1973. Masters Research Project, Department of Architecture, University of Florida, Gainesville, FL 254 pp.
- Craighead, F.C. Sr. 1969. Vegetation and recent sedimentation in Everglades National Park. *Fla. Nat.* 42:157-166.
- Craighead, F.C. Sr. 1971. *The Trees of South Florida*, Vol I: The natural environments and their succession, Uni. of Miami Press, Coral Gables, FL.
- Dachnowski-Stokes, A.P. 1930. Peat profiles of the Everglades of Florida: The stratigraphic features of the "upper" Everglades and correlation with environmental changes. *J. Wash. Acad. Sci.* 20:89-107.
- Davis, J.H. 1943a. The natural features of southern Florida, especially the vegetation of the Everglades. Bulletin No. 25, Florida Geological Survey, Tallahassee FL.
- Davis, J.H., Jr. 1943b. Vegetation of the Everglades and conservation from the point of view of the plant ecologist. *Proceedings of the Soil Science Society of Florida*, 5-A:105-113.

-DRAFT-
Minimum Water Level Criteria

- Davis, J.H. 1946. The Peat deposits of Florida -their occurrence, development and uses. Bulletin No. 30:1-247, Florida Geological Survey, Tallahassee FL.
- Davis, S.M., L.H. Gunderson, W.A. Park, J.F. Richardson, and J.E. Mattson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. In: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL.
- Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL. 826 pp.
- DeAngelis, D. L. 1994. Synthesis: Spatial and temporal characteristics of the environment. In: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL. pp. 307-322
- Dineen, J.W. 1972. Life in the tenacious Everglades. *In Depth Report* 1(5):1-10. Central and Southern Flood Control District, West Palm Beach, FL.
- Egler, F.E. 1952. Southeast saline Everglades; vegetation of Florida and its management. *Vegetation*, 3:213-265.
- EFA. Everglades Forever Act, Florida Statutes 373.4592
- Florida Department of Environmental Protection, 1997. Water Management District's Minimum flows and levels combined 1997 Priority Lists. February 16, 1998. 1p. Florida Department of Environmental Protection, Tallahassee Florida.
- Fenemma, R.A., C.J. Neidrauer, R.A. Johnson, T.K. MacVicar, and W.A. Perkins, 1994. A computer model to simulate natural Everglades hydrology. In: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL. pgs. 249-290.
- Fish, J.E., 1988. Hydrogeology, aquifer characteristics, and ground-water flow of the Surficial Aquifer System, Broward County, Florida. U.S. Geological Survey Water-Resources Investigations Report 87-4034, Tallahassee, FL, 92 p.
- Fish, J.E., and Stewart, M., 1991. Hydrogeology of the Surficial Aquifer System, Dade County, Florida. U.S. Geological Survey Water-Resources Investigations Report 90-4108, Tallahassee, FL, 50 p.
- Florida Game and Freshwater Fish Commission, Personal Communication. Letter dated May 10 1993, from Stephen Coughlin to David Swift, concerning Everglades properties managed by the FGFWFC. 7pp.
- Fox, D.D., S. Gornak, T.D. McCall, D.W. Brown and C.J. Morris. 1995. Lake Okeechobee fisheries investigations. State of Florida, Florida Game and Freshwater Fish Commission, Lake Okeechobee-Kissimmee River Project. Completion Report (Fiscal years 1992-1993 and 1994-1195). Fla. Game and Fresh Water Fish Comm., Tallahassee, Fl., 177 pgs.
- Furse, J.B. and D.D. Fox 1994. Economic fishery valuation of five vegetation communities in Lake Okeechobee, Florida. Proceedings of Annual Conference Southeast Association of Fish and Wildlife Agencies, 48, pp. 575-591.

-DRAFT-
Minimum Water Level Criteria

- Freeze, R.A. and Cherry, J.A., 1979. Groundwater. Prentice Hall, Inc., Englewood Cliffs, NJ, 604 p.
- Gleason, P. J. 1972. The origin, sedimentation, and stratigraphy of a calcite mud located in southern freshwater Everglades. Ph.D Dissertation, Pennsylvania State University, University Park PA.
- Gleason, P.J. and W. Spackman. 1974. Calcareous periphyton and water chemistry in the Everglades. In: *Environments of South Florida: Present and Past*, P.J. Gleason (Ed.), Memoir No. 2, Miami Geological Society, Miami, FL, pp. 146-181.
- Gleason, P.J. and P. Stone. 1974. Special report on the effects of recent burning of Conservation Area 3 North of Alligator Alley. South Florida Water Management District Report.
- Gleason, P.J. and P.A. Stone. 1994. Age, origin, and landscape evolution of the Everglades peatland. In: *Everglades: The Ecosystem and Its Restoration*. S.M. Davis and J.C. Ogden (Eds.), St. Lucie Press, Delray Beach, FL., chap. 7.
- Gunderson, L.H. and W. F. Loftus. 1993. Competing land uses imperil the biotic communities of a vast wetland. South Florida Research Center, Everglades National Park, Homestead, FL.
- Gunderson, L.H. and J.R. Snyder. 1994. Fire patterns in the southern Everglades. In: Davis, S.M. and J.C. Ogden (eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie Press, Delray Beach, FL. pgs. 291-306.
- Hall, C.A. 1991. Lake Okeechobee Supply-Side Management Plan. Operations and Maintenance Dept., South Florida Water Management District, West Palm Beach, FL.
- Harper, R.M. 1927. Natural Resources of South Florida. 18th annu. Rep. Florida Geological Survey, Tallahassee, FL.
- Haunert, D.E. 1988. Sedimentation characteristics and toxic substances in the St. Lucie Estuary, Florida. Technical Publication 88-10. South Florida Water Management District, West Palm Beach, FL. 40 pp.
- Havens, K.E., L.A. Bull, G.A. Warren, T.L. Crisman, E.J. Philips & J.P. Smith. 1996. Food web structure in a subtropical lake ecosystem. *Oikos*, in press.
- Hoffman, W., G.T. Bancroft, R.J. Sawicki. 1994. Foraging habits of wading birds in the Water Conservation Areas of the Everglades. In: Davis, S.M. and J.C. Ogden (eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL
- Hoffmeister, J.E., 1974. *Land from the Sea*, Miami, FL, 143 p.
- Hutchinson, G.E. 1957. A treatise on limnology, Volume.1, Geography, physics, and chemistry. John Wiley and Sons, New York, N.Y., 1015 pp.

-DRAFT-
Minimum Water Level Criteria

- Huyakorn, P.S., Mercer, J.W., and Andersen, P.F., 1986. SWICHA: A Three-Dimensional Finite Element Code for Analyzing Seawater Intrusion in Coastal Aquifers. Geotrans, Herndon, VA, 167 p.
- Jensen, J., K. Rutchey and, M. Koch and S. Narumalani 1995. Inland wetland change detection in Everglades Water Conservation Area 2A using a time series of normalized remotely sensed data. *Journal of Photogrammetric Engineering and Remote Sensing*, 61 (2):199-209.
- Jones, L.A. 1948. Soils, geology and water control in the Everglades region. Bull. Vol. 442, University of Florida Agricultural Experiment Station. Prepared in cooperation with the USDA Soil Conservation Service. Gainesville, FL, 168 pp.
- Klein, H., J.T. Armbruster, B.F. McPherson and H.J. Freiburger. 1975. Water and the south Florida environment. Water Resources Investigation 24-75. U.S. Geological Survey, Tallahassee, FL, 165 pp.
- Kohout, F.A. 1960. Cyclic flow of salt water in the Biscayne aquifer of southeastern Florida. *Journal of Geophysical Research*, V 65 (7), pp 2133-2141.
- Koszalka, E.J. 1995. Delineation of saltwater intrusion in the Biscayne aquifer, eastern Broward County, Florida, 1990. U.S. Geological Survey Water-Resources Investigations Report 93-4164.
- Light, S.S. and J.W. Dineen 1994. Water control in the Everglades: A historical perspective. In: *Everglades: The Ecosystem and Its Restoration*. S.M. Davis and J.C. Ogden (Eds.), St. Lucie Press, Delray Beach, FL, pp. 461-484.
- LOLZTG. 1988. Assessment of Emergency Conditions in Lake Okeechobee littoral Zone: Recommendations for interim management. Preliminary report by the Lake Okeechobee Littoral Zone Technical Group (LOLZTG) to John R. Wodraska, Executive Director, South Florida Water Management District, West Palm Beach, FL.
- Lietz, C., T. Richards, and R. Krulikas 1995. Water resources data, Florida, 1994, Volume 2B, South Florida Ground Water. U.S. Geological Survey Water-Data Report FL-94-2B. Miami, FL, 780 pp.
- Loftus, W.F., R.A. Johnson, and G. Anderson. 1992. Ecological impacts of the reduction of groundwater levels in the rocklands. In: *Proc. 1st Int. Conf. of Ground water Ecology*, J.A. Stafford and J.J. Simon (Eds.) American Water Resources Association, Bethesda, Md. pp.198-208.
- Loftus, W.F. and Anne-Marie Ekland. 1994. Long-term dynamics of an Everglades small-fish assemblage. In: *Everglades: The Ecosystem and Its Restoration*. S.M. Davis and J.C. Ogden (Eds.), St. Lucie Press, Delray Beach, FL, pp. 461-484.
- Loveless, C.M. 1959. A study of the vegetation of the Florida Everglades. *Ecology*, 40(1):1-9.
- MacVicar, T.K. 1985. A wet season field test of experimental water deliveries to northeast Shark River Slough. Technical Publication 85-3, South Florida Water Management District, West Palm Beach, FL.

-DRAFT-
Minimum Water Level Criteria

- McDowell, L.L., J.C. Stephens, and E.H. Stewart. 1969. Radiocarbon chronology of the Florida Everglades peat. *Soil Sci. Soc. Am. Proc.* 33:743-745.
- 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: Davis, S.M. and J.C. Ogden (Eds) 1994. *Everglades: The Ecosystem and Its Restoration*. St. Lucie press, Delray Beach, FL.
- Merritt, M. L. 1996. Assessment of saltwater intrusion in southern coastal Broward County, Florida. U.S. Geological Survey, Water Resources Investigations Report. 96-4221, Tallahassee, FL. 133 p.
- Neidrauer, C.J. and R.M. Cooper. 1989. A two-year field test of the rainfall plan: A management plan for water deliveries to Everglades National Park, July 1985-1987. Technical Publication 89-3. South Florida Water Management District. West Palm Beach, FL, 98 pp.
- Ogden, J.C., W. F. Loftus and W. B. Robertson, Jr. 1987. Woodstorks, wading birds and freshwater fishes. Statement Paper. U.S. Army Corps of Engineers, General design memorandum on modified deliveries to Everglades National Park, South Florida Research Center, Homestead, FL.
- Olmstead, I.C. and L.L. Loope. 1984. Plant communities of Everglades National Park. In: *Environments of South Florida: Present and Past*, P.J. Gleason (Ed.), Memoir No. 2, Miami Geological Society, Miami, FL., pp. 167-184.
- Olmsted, I. C., L.L. Loope and R.E. Rintz. 1980. A survey and baseline analysis of aspects of the vegetation of Taylor Slough, Everglades National Park. South Florida Research Center Technical Report T-586. Everglades National Park, Homestead, FL.
- Parker, G.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. Water Supply Paper 1255, U.S. Geological. Survey, U.S. Government Printing Office, Washington, D.C., 965 pp.
- Perkins, W.A. and T.K. MacVicar. 1991. A computer model to simulate natural south Florida hydrology, Draft report, South Florida Water Management District, West Palm Beach, FL.
- Pesnell, G.L. and R.T. Brown, III. 1973. The vegetation of the Lake Okeechobee, Florida (map). Central & Southern Florida Flood Control District. West Palm Beach, FL.
- Puri, H.S. and R.O. Vernon. 1964. Summary of the geology of Florida and guidebook to the classic exposures. *Fla. Geol. Surv. Spec. Publ.*, No. 5, 312 pp.
- Restrepo, J., Bevier, C. and Butler, D. 1992. A three dimensional finite difference ground water flow model of the Surficial Aquifer System, Broward County, Florida. Tech. Pub. 92-05, South Florida Water Management District, West Palm Beach, FL.

-DRAFT-
Minimum Water Level Criteria

- Richardson, C.J. and C.B. Craft. 1990. Phase One: A preliminary assessment of nitrogen and phosphorus accumulation and surface water quality in Water Conservation Areas 2A and 3A of South Florida. Publication 90-01. School of Forestry and Environmental Studies, Duke Wetland Center, Duke University, Durham, NC.
- Richardson, J.R., T.T. Harris, and K.A. Williges. 1995. Vegetation correlations with nvarious environmental parameters in the Lake Okeechobee littoral marsh ecosystem. *Archiv. fur Hydrobiologie, Advances in Limnology*, vol. 45, pp.41-61.
- Robertson, W.B. Jr. 1953. A survey of the effects of fire in Everglades National Park. Everglades National Park, National Park Service, United States Department of the Interior, Homestead, FL.
- Robertson, W. B. and J.A. Kushlan. 1984. The southeastern Florida avifauna. In: Gleason (ed.) *Environments of South Florida: Past and Present*. Miami Geological Society, Miami FL.
- Rutchev, K. and L. Vilchek 1994. Development of an Evergaldes vegetation map using SPOT Image and the Global Positioning System. *Journal of Photogrammetric Engineering and Remote Sensing*, 60 (6):7767775.
- Schomer, N.S. and R.D. Drew. 1982. An ecological characterization of the lower Everglades, Florida Bay, and the Florida Keys. FWS/OBS-82/58.1. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., 246 pp.
- Schortemeyer, J. L. 1980. An evaluation of water management practices for optimum wildlife benefits in Conservation Area 3A. Florida Game and Freshwater Fish Commission, Ft. Lauderdale, FL.
- Science Subgroup, 1994. South Florida ecosystem restoration: scientific information needs. Draft Sept. 27, 1994. Management and Coordination Working Group, Interagency Task Force on the South Florida Ecosystem.
- Scientific Working Group. 1995. Record of the proceedings of the Scientific Working Group meetings of August 29-31, 1994 conducted at the Palm Beach Hilton Hotel, West Palm Beach, Florida in support of the Lower East Coast Regional Water Supply Plan, South Florida Water Management District, West Palm Beach, FL.
- Sheng, Y.P. and H.K. Lee. 1991. Computation of phosphorus flux between the vegetation area and the open water in Lake Okeechobee. Final Report, Contract Investigation. Prepared for South Florida Water Management District, West Palm Beach, FL.
- Shine, M., D. Padgett, and W.M. Barfknect. 1989. Ground water resource assessment of eastern Palm Beach County, Florida. Technical Publication #89-4, South Florida Water Management District, West Palm Beach, FL.
- Smith, J.P., J.R. Richardson & M.W. Callopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. *Archiv fur Hydrobiologie, Advances in Limnology*, 45: 247-285.

-DRAFT-
Minimum Water Level Criteria

- SFWMD. 1987. Staff Manual for the Management of Water Shortages. Operations and Maintenance Dept., South Florida Water Management District. West Palm Beach, FL.
- SFWMD. 1989. Interim Surface Water Improvement and Management (SWIM) Plan for Lake Okeechobee. South Florida Water Management District. West Palm Beach, FL.
- SFWMD. 1992. Draft Surface Water Improvement and Management Plan for the Everglades. Planning Department, South Florida Water Management District. WPB, FL.
- SFWMD 1993a. Surface Water Improvement and Management (SWIM) Plan. Update for Lake Okeechobee, Volume 1, Planning Document. South Florida Water Management District, West Palm Beach FL. January, 1993
- SFWMD. 1993b. Public Water Supply Permit Renew, City of Hallandale. South Florida Water Management District. WPB, FL.
- SFWMD, 1994. Lower West Coast Water Supply Plan. Planning Department, South Florida Water Management District. West Palm Beach, FL. February 1994.
- SFWMD. 1995a. An update of the Surface Water Improvement and Management Plan for Biscayne Bay. Planning Dept. South Florida Water Management District. WPB, FL.
- SFWMD. 1995b. District Water Management Plan, Volume 1, Planning Dept. South Florida Water Management District. West Palm Beach, FL, April 1995.
- SFWMD, 1997. Surface Water Improvement and Management (SWIM) Plan- Update for Lake Okeechobee, Vol. 1, Planning Document..Planning Department, South Florida Water Management District. West Palm Beach, FL.
- SFWMD, 1997. Draft Lower East Coast Interim Plan, .Planning Department, South Florida Water Management District. West Palm Beach, FL.
- Sonenshein, R.S., and Koszalka, E.J. 1995. Water-table trends and saltwater intrusion in the Biscayne aquifer, Dade County, Florida, through 1993. U.S. Geological Survey (in press).
- Spackman, W., C.P. Dolson, and W. Riegel. 1966. Phytogenic organic sediments and sedimentary environments in the Everglades-Mangrove complex, Part 1: Evidence of a transgression sea and its effects on environments of the Shark River area of southwestern Florida. *Palaeontographica*. 117(8):135-152.
- Stephens, J.C. and L. Johnson. 1951. Subsidence of organic soils in the upper Everglades region of Florida. Soil Science Society of Florida proceedings, Vol. XI, pp. 191-237.
- Stephens, J.C. 1984. Subsidence of Organic soils in the Florida Everglades - a review and update. In: Gleason (ed.) *Environments of South Florida: Past and Present*. Miami Geological Society, Miami FL.

-DRAFT-
Minimum Water Level Criteria

- Stone, P.A. 1978. Floating Islands--Biogeomorphic Features of Hillsboro Marsh, Northeastern Everglades, Florida, M.A. thesis, Florida Atlantic University, Boca Raton, FL.
- Stone, P.A. and P.J. Gleason. 1983. Environmental and paleoenvironmental significance of organic sediments (peats) in southeastern United States. In: *Variation in Sea Level on the South Carolina Coastal Plain*, D.J. Colquhoun (Ed.) Department of Geology, University of South Carolina, Columbia, pp. 121-141.
- Swift, D. R., C. Anclade, I.H. Kantrowitz. 1987. Algal blooms in Lake Okeechobee, Florida and management strategies to mitigate eutrophication. *National Water Summary 1987- Hydrological Events and Water Supply and Use*. U.S. Geological Survey Water Supply Paper 2350.
- Swift, D.R. and R.B. Nicholas. 1987. Periphyton and water quality relationships in the Everglades Water Conservation Areas. Technical Publication 87-2. South Florida Water Management District, West Palm Beach, FL.
- Tarver, D.P., J.A. Rodgers, M.J. Mahler and R.L. Lazor. 1986. Aquatic and Wetland Plants of Florida. Bureau of Aquatic Plant Research and Control, Florida Department of Natural Resources, Tallahassee, FL.
- Taylor, D.L. 1981. Fire history and fire records for Everglades National Park 1948-1979. South Florida Research Center Report T-619, U.S. Department of Interior, National Park Service, (April), 121 pp.
- Todd, D.K. 1980. Groundwater Hydrology. John Wiley & Sons, NY, 535 pp.
- Tropical BioIndustries, Inc. 1990. Hydroperiod conditions of key environmental indicators of Everglades National Park and adjacent East Everglades area as guide to the selection of an optimum water plan for Everglades National Park. Tropical BioIndustries, Inc., Miami, FL.
- USACE. 1991. Central and Southern Florida Project, Water control plan for Lake Okeechobee and Everglades Agricultural Area, Jacksonville District,, Jacksonville, FL., March 1991.
- USACE. 1992. Water control plan for Water Conservation Areas-Everglades National Park, and ENP-South Dade Conveyance System, Central and Southern Florida Project for Flood Control and other Purposes, Jacksonville District,, Jacksonville, FL., October 1992.
- USACE. 1994. Central and Southern Florida Project. Final Integrated General Reevaluation Report and Environmental Impact Statement. Canal 111 (C-111), South Dade County, Florida., Jacksonville District,, Jacksonville, FL., May 1994.
- Wade, D.D., J.J. Ewel, and R. Hofstetter. 1980. Fire in south Florida ecosystems. General tech. Report SE-17. U.S. Dept. of Agriculture Forest service Asheville, N.C.
- Werner, H.W. 1976. Distribution, habitat, and origin of the Cape Sable seaside sparrow. Masters thesis. University of South Florida, Tampa, FL.

-DRAFT-
Minimum Water Level Criteria

- White, W.A. 1970. The geomorphology of the Florida peninsula. *Florida Bureau of Geology Bulletin Number 51*.
- Worth, D. F. 1988. Environmental responses of Water Conservation Area 2A to reduction in regulation schedule and marsh drawdown. Technical Publication 88-2. South Florida Water Management District, West Palm Beach, FL.
- Wu, Yegang, F. Sklar, K. Gopu, K. Rutchey. 1996. Fire simulations in the Everglades landscape using parallel programing. In: Ecological Modeling (in press).
- Zaffke, M. 1983. Plant communities of Water Conservation Area 3A: Baseline documentation prior to the operation of S-339 and S-340. Tech. Memo. South Florida Water Management District, West Palm Beach, FL.