SURFACE WATER
IMPROVEMENT AND MANAGEMENT PLAN FOR
THE EVERGLADES

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

PROTECTOR OF THE EVERGLADES SINCE 1949

SUPPORTING INFORMATION DOCUMENT

March 13, 1992

***
**
*

SURFACE WATER IMPROVEMENT
AND MANAGEMENT PLAN

FOR

THE EVERGLADES

SUPPORTING INFORMATION DOCUMENT

Issued in compliance with the
Surface Water Improvement and Management Act
(Sections 373.451 - 373.4595, Florida Statutes)

and

Rule 17-43.035, Florida Administrative Code
(Florida Department of Environmental Regulation

and

Marjory Stoneman Douglas Everglades Protection Act
(Section 373.4592, Florida Statutes)

South Florida Water Management District

March 13, 1992

DRAFT
Surface Water Improvement and Management Plan For the Everglades
March 13, 1992

Everglades SWIM Plan Manager:
Paul J. Whalen

Principal Authors:

Paul J. Whalen	Supervising Professional: Overview, Implementation Programs and Projects, Costs & Revenues, FP&L Projects
Joel VanArman	Supervising Professional: Overview, Critical Issues, Goals, Objectives, and Strategies
John Mulliken	Critical Issues
Dave Swift	EAA - WCA
Sarah Bellmund	C-111 - ENP
Dewey Worth	Monitoring and Research
Thomas D. Fontaine, Ph.D.	STA Model Documentation
Lynn Gulick	Appendices
Sandra Formati	Graphics, Corrections, Editing, and Formatting

Other Contributors:

These documents are the products of an effort by more than 100 members of the District staff, five private consulting companies, two technical advisory groups and representatives of various local, state, and federal agencies. The District staff wish to express its sincere appreciation for the dedication and commitment of all who participated in this task.

List of Abbreviations

ac-ft=	acre-feet
ASR=	aquifer storage and recovery
BMPs=	best management practices
BOR=	Basis of Review
cfs=	cubic feet per second
C&SF Project=	Central and Southern Florida Project for Flood Control and Other Purposes
CSFFCD=	Central and Southern Florida Flood Control District
CWA=	Clean Water Act
DACS=	Florida Department of Agriculture and Consumer Services
DCA=	Florida Department of Community of Affairs
DDM=	Detailed Design Memorandum
DER=	Florida Department of Environmental Regulation
DERM=	Department of Environmental Resource Management (Dade County)
DNR=	Florida Department of Natural Resources
DOI=	U.S. Department of Interior
EAA=	Everglades Agricultural Area
EDD=	Everglades Drainage District
EIS=	Environmental Impact Statement
ENP=	Everglades National Park
EPA=	Everglades Protection Area (WCA-1, WCA-2, WCA-3, ENP)
ERC=	Florida Environmental Regulatory Commission
FEMA=	Federal Emergency Management Administration
FGFWFC=	Florida Game and Freshwater Fish Commission
FNAI=	Florida Natural Areas Inventory
FPL=	Florida Power and Light Company
ft=	feet
GDM=	General Design Memorandum
gm=	gram
IAP=	Interim Action Plan
IFAS=	Institute of Food and Agricultural Science (University of Florida)
kV=	kilovolts=1000 volts
HRS=	Florida Department of Health and Rehabilitative Services
LEC=	Lower East Coast
LOTAC=	Lake Okeechobee Technical Advisory Council
LWC=	Lower West Coast
m=	meters
mg/l=	milligrams per liter
msl=	mean sea level
MOA=	Memorandum of Agreement
MTF=	Melaleuca Task Force
NAS=	National Academy of Sciences
NEPA=	National Environmental Policy Act
NGVD=	National Geodetic Vertical Datum
NMFS=	National Marine Fisheries Service
NPDES=	National Pollution Discharge Elimination System
NPS=	National Park Service
OFW=	Outstanding Florida Water
ONRW=	Outstanding National Resource Water

List of Abbreviations (Continued)

ORV =	off-road vehicle
P2000 =	Preservation 2000 program
ppb =	parts per billion
RCRA =	Resources Conservation and Recovery Act
SCS =	Soil Conservation Service
SFRPC =	South Florida Regional Planning Council
SFWMD =	South Florida Water Management District
SRF =	systematic reconnaissance flights
SOR =	Save Our Rivers
STA =	Stormwater Treatment Area
SWFRPC =	Southwest Florida Regional Planning Council
SWIM =	Surface Water Improvement and Management
TCRPC =	Treasure Coast Regional Planning Council
TIITF =	Trustees of the Internal Improvement Trust Fund
USDA =	United States Department of Agriculture
USCOE =	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
yr =	year

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

(This page intentionally left blank)

EVERGLADES SWIM PLAN

Supporting Information Document

I. LEGAL BACKGROUND OF EVERGLADES SWIM PLAN

A. INSTITUTIONAL AUTHORIZATIONS

Many governmental entities exercise water management jurisdiction in the Everglades SWIM planning area. These entities operate at federal, state, regional, and local levels. This section of the SWIM plan focuses on the governmental entities which have been identified as the principal participants in the SWIM planning and implementation process. Indian tribes make up an additional entity which also must be considered in the SWIM process.

The SWIM Act requires that plans include "an identification of all governmental units that have jurisdiction over the water body and its drainage basin within the approved surface water improvement and management plan area, including local, regional, state, and federal units;" (State of Florida, 1987; 1989a). Governmental units within the Everglades SWIM plan area are listed in **Table 1.**

The governmental entities with water management authority of primary importance to the Everglades SWIM planning process include, on a regional or state level, the South Florida Water Management District, the Regional Planning Councils, the Florida Department of Environmental Regulation, the Florida Game and Fresh Water Fish Commission, the Department of Community Affairs, and the Department of Natural Resources. On the federal level, the main participants include the U.S. Army Corps of Engineers (USCOE), the U.S. Environmental Protection Agency (EPA), and several agencies within the Department of the Interior, including the National Park Service (NPS) and the United States Fish and Wildlife Service (USFWS).

The Indian tribes of importance to the Everglades SWIM plan consist of the Miccosukee and Seminole tribes. These tribes exert water management rights on tribal lands which are superior to the water management authority of state, regional, and local governments.

A general discussion of each of the identified entities appears below. The discussion emphasizes those aspects of each entity's jurisdiction which are pertinent from a SWIM planning perspective.

1. Regional

South Florida Water Management District. The South Florida Water Management District (District) is the successor agency of the Everglades Drainage District, the Okeechobee Flood Control District, and the Central and Southern Florida Flood Control District (CSFFCD).

<u>Everglades Drainage District</u>. The Florida Legislature established the Everglades Drainage District in 1913 and granted it authority over drainage and reclamation of land for agricultural and sanitary purposes, public utility, and public benefit (State of Florida, 1913).

Table 1. Governmental Units.

Section 373.453(2)(b), F.S., requires that the SWIM Plan contain an "identification of all governmental units that have jurisdiction over the water body and its drainage basin within the approved surface water improvement and management plan area, including local, regional, state, and federal units." This chart lists those governmental units with jurisdiction over Everglades National Park, the Water Conservation Areas, and their drainage basins.

A. Federal
- Army Corps of Engineers
- Department of Agriculture
  - Soil Conservation Service
- Department of Interior
  - Fish and Wildlife Service
  - National Park Service
  - U.S. Geological Survey
  - Marine Fisheries Service
  - Bureau of Indian Affairs
- Environmental Protection Agency

B. Indian
- Miccosukee Indian Nation
- Seminole Indian Nation

C. State
- Department of Agricultural and Consumer Services
  - Soil and Water Conservation Services
- Department of Community Affairs
- Department of Environmental Regulation
- Department of Health and Rehabilitative Services
- Department of Natural Resources
- Department of Transportation
- Florida Game and Fresh Water Fish Commission

D. Regional
- South Florida Water Management District
- South Florida Regional Planning Council
- South West Florida Regional Planning Council
- Treasure Coast Regional Planning Council
- EAA Everglades Protection District

E. Local
1. County
   - Broward County
   - Collier County
   - Dade County
   - Glades County
   - Hendry County
   - Monroe County
   - Martin County
   - Palm Beach County
2. Municipal
   - Broward County
     - Cooper City
     - Coral Springs
     - Lauderhill
     - Margate
     - Miramar
     - North Lauderdale
     - Parkland
     - Pembroke Pines
     - Plantation
     - Sunrise
     - Tamarac
   - Dade County
     - Florida City
     - Homestead
     - Miami Springs
     - Sweetwater
   - Hendry County
     - Clewiston

E. Local (Continued)
2. Municipal (Continued)
   - Palm Beach County
     - Belle Glade
     - Boca Raton
     - Boynton Beach
     - Delray Beach
     - Hypoluxo
     - Lake Worth
     - Lantana
     - Royal Palm Beach
     - West Palm Beach
3. Drainage Districts (Ch. 190 and 298 Districts)
   - Broward County
     - Central Broward Drainage District
     - Coral Springs Improvement District
     - Indian Trace Improvement District
     - North Lauderdale Water Control District
     - North Springs Improvement District
     - Old Plantation Water Control District
     - Plantation Acres Improvement District
     - South Broward Drainage District
     - Sunshine Drainage District
     - West Lauderdale Water Control District
     - West Parkland Water Control District
   - Glades County
     - Disston Island Conservancy District
     - Flaghole Drainage District
     - Newhall Drainage District
     - Sugarland Drainage District
   - Hendry County
     - Bolles Drainage District
     - Clewiston Drainage District
     - Hendry-Hilliard Drainage District
     - Ritta Drainage District
     - South Florida Conservancy District
     - Sugarland Drainage District
   - Palm Beach County
     - Acme Improvement District
     - Bolles Land Water Control District
     - East Beach Water Control District
     - East Shore Water Control District
     - Gladeview Drainage District
     - Highland Glades Drainage District
     - Islands Flood Control District
     - Indian Trail Water Control District
     - Lake Worth Drainage District
     - North Palm Beach Heights Water Control District
     - Northern Palm Beach County Water Control District
     - Pahokee Water Control District
     - Pal Mar Water Control District
     - Pelican Lake Water Control District
     - Pine Tree Water Control District
     - Ritta Drainage District
     - Seminole Water Control District
     - Shawano Drainage District
     - South Florida Conservancy District
     - South Shore Drainage District

Okeechobee Flood Control District. The Florida Legislature established the Okeechobee Flood Control District in 1929 and authorized it to establish, construct, operate, and maintain canals, levees, dams, locks, and reservoirs, and to improve natural waterways to control and regulate Lake Okeechobee and the Caloosahatchee River; in addition, the District had responsibilities to cooperate with the federal government in flood control and navigation (State of Florida, 1929).

Central and Southern Florida Flood Control District. The Florida Legislature established the Central and Southern Florida Flood Control District in 1949 and authorized it to operate under the provisions of Chapter 378, Florida Statutes. Its authority under this statute included cooperation with the federal government for flood control, reclamation, conservation, and allied purposes, planning, construction, and operation of works, and water quality protection in conjunction with the Department of Health. The Legislature dissolved and terminated the Everglades Drainage District and the Okeechobee Flood Control District in 1949 with the creation of the Central and Southern Florida Flood Control District (State of Florida, 1949).

The Florida Legislature created the South Florida Water Management District in 1972 with the enactment of the Water Resources Act, and authorized the District to carry out water management responsibilities under Chapter 373, Florida Statutes (State of Florida, 1972). This legislation created the five water management districts, including the South Florida Water Management District. In 1976, the name of the Central and Southern Florida Flood Control District was changed to the South Florida Water Management District along with a corresponding boundary change (State of Florida, 1976).

As specified in Section 373.103 (2) Florida Statutes, the District also functions as the local cooperator for the federally authorized Central and Southern Florida Project for Flood Control and Other Purposes. Under Rule 40E[-]1.103 Florida Administrative Code, the District's water management authority includes flood protection, water supply, water quality protection, and environmental protection and enhancement (Section 373.016, Florida Statutes).

Regional Planning Councils. Three regional planning councils have jurisdiction within the Everglades SWIM planning area. They are the South Florida Regional Planning Council, the Southwest Florida Regional Planning Council, and the Treasure Coast Regional Planning Council. The regional planning councils are responsible for developing regional policies, conducting comprehensive planning activities, providing technical planning assistance to local governments, and determining the impacts of proposed developments of regional scope on communities and natural resources (CH_2MHill, 1989).

2. State

Department of Environmental Regulation. The Department of Environmental Regulation (DER) is the lead environmental agency in the state of Florida. The DER's regulatory jurisdiction as defined under Chapter 403, Florida Statutes, includes discharges to surface and ground waters, dredge and fill, solid and hazardous waste facilities, public water systems, underground injection, and construction of certain water wells (Section 403.061, Florida Statutes. The DER also has authority to classify water bodies and to regulate discharges to ensure that they are appropriate to the water body's designation. The DER shares jurisdiction over stormwater runoff with the water management districts (State of Florida, 1989a).

The DER also has oversight responsibilities for the five regional water management districts, and authority to develop and implement water use plans in cooperation with the water management districts as defined in Section 373.026, Florida Statutes.

Florida Game and Fresh Water Fish Commission. Article IV, Section 9, of the Florida Constitution created the Florida Game and Fresh Water Fish Commission (FGFWFC). The FGFWFC exercises the regulatory and executive powers of the state, and is charged with the management, protection, and conservation of wild animal life and fresh water aquatic life. The FGFWFC also has jurisdiction over waters of the state whose quality or quantity will affect wild animal life or freshwater aquatic life, regulates hunting and fishing and identifies and manages state endangered and threatened species as specified in Section 372.072, Florida Statutes.

Department of Natural Resources. The Department of Natural Resources (DNR) is one of the state's conservation agencies and directs programs for land conservation and reclamation, recreational land, animal and plant protection, saltwater fishery protection, oil and gas (Chapters 253, 258, 370, 275 and 377 Florida Statutes). The DNR, through the Board of Trustees of the Internal Improvement Trust Fund is authorized under Chapter 253, Florida Statutes to acquire and manage state-owned lands. These lands include those which are environmentally endangered or significant from a conservation standpoint. The DNR also acquires and manages state parks and recreation areas, and manages and administers marine resources, including aquatic preserves (Chapters 253, 258, 370, and 375, Florida Statutes).

Department of Community Affairs. The Department of Community Affairs (DCA) is the lead state agency responsible for growth management planning. The DCA's responsibilities include jurisdiction over developments of regional impact and areas of critical state concern, and review and comment on local government comprehensive plans (Florida Bar Association, 1988). DCA supervises the administration, rule promulgation, and enforcement of the Environmental Land and Water Management Act (Chapter 380, Florida Statutes) and also administers the Local Government Comprehensive Planning and Land Development Regulation Act under Chapter 163, Florida Statutes, plus responsibilities such as the Federal Emergency Management Administration (FEMA), hurricane evacuation and others.

Department of Agriculture and Consumer Services. The Department of Agriculture and Consumer Services inquires into the needs of agriculture in the state and makes recommendations to the Governor and the Legislature. It also performs all regulatory and inspection services relating to agriculture except agriculture education, demonstration, research and those regulatory functions which primarily protect the public health. The Department of Agriculture and Consumer Services may compile, publish and disseminate information and pertinent data on crops, livestock, poultry and agricultural products and may provide matching funds with other agencies. The dairy interests of the State are protected by the Department of Agriculture and Consumer Services. The Department of Agriculture and Consumer Services regulates open burning in connection with rural land-clearing agricultural or forestry operations, except as to fires for cold or frost protection for pollution purposes (Florida Statutes, Chapter 570).

Department of Health and Rehabilitative Services. The Department of Health and Rehabilitative Services is responsible for onsite sewage disposal systems. The Department of Health and Rehabilitative Services issues permits for the construction or installation of onsite sewage disposal systems. (Florida Statutes. Chapter 381; Section 381.272).

3. Federal

Department of the Interior. The Department of Interior (DOI) manages and protects national natural land and water resources. Several agencies within the DOI are involved with natural resource management. They include: 1) the Fish and Wildlife Service; 2) the National Park Service; 3) the U.S. Geological Survey; and 4) the Bureau of Indian Affairs (Greenhorne and O'Mara, 1989). Some of these agencies are discussed in more detail below.

National Park Service and Everglades National Park. The National Park Service manages and administers the operations of the National Park System, including Everglades National Park (ENP). It is responsible for conservation of scenery, natural and historical objects, and wildlife (Greenhorne and O'Mara, 1989; United States Code, Title 16, Section 410).

The ENP was authorized in 1934 (State of Florida, 1934; United States Code, Title 16 Section 410). Under this act, the National Park Service, under the direction of the Secretary of the Interior, has the authority to administer, protect, and develop ENP. In 1935 the Florida Legislature set aside lands for ENP for the purposes of protecting and breeding native plant life and animal wild life (State of Florida, 1935).

The federal authorizations which apply to the ENP are summarized in **Table 2**. The authorizations of interest to the SWIM planning effort are those which modified the water deliveries to the ENP, particularly the Supplemental Appropriations Act of 1984 that authorized an experimental program of water deliveries. In 1989, Congress authorized the expansion of ENP boundaries through the adoption of the Everglades National Park Expansion and Protection Act (United States Congress, 1989).

U.S. Fish and Wildlife Service. The U.S. Fish and Wildlife Service (USFWS) has jurisdiction over the management of federally mandated threatened and endangered species. This agency is charged with the conservation, protection, and enhancement of fish and wildlife and their habitats. The FWS conducts research on fish and wildlife development, manages migratory birds, conducts law enforcement and damage control activities, and consults on water resource development projects (Greenhorne and O'Mara, 1989). The USFWS manages the National Wildlife System. In South Florida, this includes the Arthur R. Marshall Loxahatchee National Wildlife Refuge (WCA-1) and the Crocodile Lake National Wildlife Refuge. WCA-1 is managed under an agreement with the then Central and Southern Florida Flood Control District, subject to project purposes.

National Marine Fisheries Service. The National Marine Fisheries Service, under the Department of Commerce, conserves and manages the fishing resources found off the coasts of the United States and the anadromous species and continental shelf fishery resources of the United States (United States Code. Title 16, Section 1801).

U.S. Geological Survey. The U.S. Geological Survey (USGS) classifies public lands and examines the natural resources. In cooperation with other federal and local governmental entities, the USGS assists in a cooperative effort to monitor and investigate projects in south Florida which involve surface and subsurface geologic

Table 2. Everglades National Park (ENP) Authorizations.

ACTION	DESCRIPTION	NOTES
Act of Aug. 25, 1916. 16 USCS s. 1.	National Park Service (NPS) created as an agency of the Department of the Interior (DOI).	Secretary of the Interior is responsible for maintaining our national parks.
Act March 1, 1929. 45 Stat. 1443 (1929) (not classified to code).	Directed Secretary of the DOI to investigate the desirability and practicability of establishing a national park in the Everglades of Florida.	
Secretary of Interior's report to Congress Dec. 3, 1930.	Report recommended the desirability of a national park in the area of the Everglades.	
Ex. Ord. No. 6166. 5 USCS s. 901 (1933).	Transfer of functions to the NPS in the DOI.	Administration of public buildings, reservations, national park, national monuments, and national cemeteries, now under the NPS.
Act March 2, 1934. ch. 38 s. 1, 48 Stat. 389.	The Office of National Parks, buildings, and reservations, was designated as NPS.	
Everglades National Park Act. ch. 371, 48 Stat. 816 (1934) (codified at 16 USCS s. 410).	Act authorizing Everglades National Park (ENP). Authorization to acquire approximately 2,000 square miles in the region of the Everglades of Dade, Monroe, and Collier counties.	ss. 410 to 410h were not made public law. Purchase of said lands shall not be by appropriation of public money, but shall be secured by public or private donation. Requires reservation of wilderness and prohibits development for park visitors which will interfere with the preservation of flora and fauna.
Acceptance of lands. ch. 371 s. 2, 48 Stat. 816 (1934) (codified at 16 USCS s. 410 a).	Secretary of the Interior is authorized to accept title of above lands on behalf of United States.	Florida to cede jurisdiction to the United States.
Administration, Protection, and Development ch. 732, 50 Stat. 742 (1937) (codified at 16 USCS s. 410b).	Under the direction of the Secretary of the Interior by the NPS.	
Acceptance and protection; publication of establishment order. ch. 508, 58 Stat. 794 (1944) (codified at 16 USCS s. 410d).	Purpose to protect scenery, wildlife, and other natural features. Upon execution of the provisions in this section the ENP shall be established by order of the Secretary which shall be published in the Federal Register.	Exclusive jurisdiction over ENP was accepted by the Secretary of the Interior in 1952 (17 Fed. Reg. 169).
Comprehensive Report on Central and Southern Florida for Flood Control and other purposes. House Doc. #643 Feb. 19, 1948.	Preliminary examination and survey of, and a review of reports on, rivers, lakes, and canals of central and southern Florida for flood control and other purposes.	Recognizes ENP and acknowledges that not all aspects of Park were examined because Park was just recently established. Views Project and Park plans as complementary features of Federal activity.
Acquisition of additional lands. ch. 659, 63 Stat. 733 (1949) (codified at 16 USCS s. 410e-410h).	Secretary of the Interior is authorized within the boundaries of ENP and with any funds made available for that purpose, to procure lands or interests by purchase or otherwise subject to the right of retention by owners of the lands, interests in oil, gas, mineral rights, etc.	Deed #19035 executed Dec. 28, 1944 by the Trustees of the Internal Improvement Fund of the State of Florida. Accepted by the Secretary of the Interior on March 14, 1947.
Lands included in the boundaries of the Everglades. Pub. L. No. 85-482, 72 Stat. 280 (1958) (codified at 16 USCS ss 410i-410p).	Land and water within these boundaries shall continue to be administered as ENP; however, the land and water therein not in Federal ownership shall be administered as part of the Park only after being acquired.	This section is a listing of the boundaries of the Park.
Drainage of lands; rights of way. Pub. L. No. 85-482, 72 Stat. 280 (1958) (codified at 16 USCS s. 410n).	Secretary of the Interior shall permit drainage, construction, operation and maintenance of artificial works required by Florida for reclamation.	This work to be done by drainage district. Must submit a master plan and must be approved by the State of Florida. Must not be detrimental to preservation and propagation of the flora and fauna of the park.
Conveyance to the State of Florida. Pub. L. No. 85-482, 72 Stat. 280 (1958) (codified at 16 USCS s. 410o).	Authorization to transfer to the State of Florida by quitclaim deed, the land, water, and interests therein, previously acquired by the U.S. for the Park but not included within the boundaries as set in s. 410i in exchange for the conveyance by the State of Florida, of all land, water, and interests therein, owned by the State and within the boundaries set in s. 410i.	
Appropriations authorized. Pub. L. No. 85-482, 72 Stat. 280 (1958) (codified at 16 USCS s. 410p).	a. Authorization to appropriate funds required (not more than $22,000,000) for acquisition of land, water, and interest, within the boundaries of the Park. b. Authorized $700,200 for acquisition of privately owned lands within Park boundaries.	a. Amendment Sept. 26, 1970 substituted $22,000,000 for $2,000,000.
Additional Lands. Pub. L. No. 86-269, 73 Stat. 553 (1959) (codified at 16 USCS s. 410q).	Authorization to accept on behalf of U.S. title of particular tracts in the Park, to exchange other tracts outside of the Park to the owners.	Tracts involved are "R" and "S" which lie west of the right-of-way of State Rd. #29 etc, to exchange tract "L" etc.

Table 2. Everglades National Park Authorizations (Continued).

ACTION	DESCRIPTION	NOTES
Rules and Regulations. Pub. L. No. 86-269, 73 Stat. 553 (1959) (codified at 16 USCS s. 410r).	States all lands and submerged lands titled to U.S. under 410 shall be subject to all laws and regulations pertaining to ENP.	
Additional Lands. Pub. L. No. 86-681, 74 Stat. 577 (1960) (codified at 16 USCS s. 410r-1).	Acquisition of land conveyed by three Collier deeds in 1951, and 1952 to the Trustees of the Internal Improvement Trust Funds (TIITF).	Deeds are dated Dec. 12, 1951, Dec. 26, 1951 and March 21, 1952; recorded in deed book 22, p 240, deed book 22, p 244, and deed book 39, p 25, in Collier County.
Rules and Regulations. Pub. L. No. 86-681, 74 Stat. 577 (1960) (codified at 16 USCS s. 410r-2).	All lands and submerged lands title to which is accepted by the Secretary of DOI pursuant to the provisions of this Act shall become parts of the ENP and shall be subject to all laws and regulations applicable thereto.	
Additional lands. Pub. L. No. 88-588, 78 Stat. 933 (1964) (codified at 16 USCS s. 410r-3).	Acceptance of a transfer from the Administrator of the Farmers Home Adm., U.S. Dept. of Agriculture of approximately 4,420 acres.	Masters deed dated Dec. 21, 1962 in the proceeding entitled "The Connecticut Mutual Life Ins. Co. v. Toni Iori..." No. 61c-3823 in the Circuit Court of the 11th Judicial Circuit of Fla., in and for Dade County.
Appropriation authorized for reimbursement of revolving fund. Pub. L. No. 88-588, 78 Stat. 933 (1964) (codified at 16 USCS s. 410r-4).	Appropriation not in excess of $452,000, authorized to reimburse the fund for costs incurred by the Farmers Home Adm. with the previously mentioned property.	
Amendment regarding acquisition of lands. Pub. L. No. 91-428, 84 Stat. 885 (1970) (codified at 16 USCS s. 410j).	Deleted a proviso that no parcel within a described area "shall be acquired without the consent of its owner so long as it is used exclusively for agricultural purposes.	
Flood Control Act of 1965. Pub. L. No. 89-298	Provides for pumping water from east of L-67 extension into Park.	
Flood Control Act of 1968. Pub. L. No. 90-483, 62 Stat. 1171.	Further modifies the project for Central and Southern Florida in accordance with S.D. 101 and H.D. 369.	Provides for conservation and conveyance of additional water supplies for ENP, for agricultural and urban needs, recreation, and other purposes.
Appropriation amendment. Pub. L. No. 91-428, 84 Stat. 885 (1970) (codified at 16 USCS s. 410p).	This amendment changed the amount of appropriation from $2,000,000 to $22,000,000.	
River Basin Monetary Authorizations and Miscellaneous Civil Works Amendments. Pub. L. No. 91-282, 84 Stat. 310 (1970). (uncodified).	a. Clarifies what the C&SF Project must deliver to ENP to guarantee approximately one-sixth of the water made available by the project. b. Set up cost sharing. c. Accelerate construction of specified works needed to bring water into the Taylor Slough and eastern panhandle of the Park. d. Constructing borrow canal L-70W and enlarging 119-W. e. Construct as soon as possible two canals and pumping stations linking water supplies from the WCA with the existing South Dade system.	Senate Report 91-895, 91st Congress to accompany House Report 15166.
Endangered American Wilderness Act of 1978. Pub. L. No. 95-237 s. 1, 92 Stat. 40 (1978) (codified at 16 USCS s. 1132 et seq.).	Everglades Wilderness, Everglades National Park, Florida.	Designation of ENP as a Wilderness Park.
Water Resources, Conservation, Development and Infrastructure Improvement and Rehabilitation Act of 1983. Supplemental Appropriations Act of 1984. Pub. L. No. 98-181, 97 Stat. 1292-1293 (1983).	a. Authorizes the Secretary with concurrence of SFWMD and Director of NPS to modify the schedule for delivery of water from the C&SFP to ENP and to conduct an experimental program for delivery of water to the Park. b. Authorizes Secretary to make modifications in Comprehensive Plan for flood control as needed to restore natural flow of water. c. Secretary is authorized to acquire such lands as are necessary to accomplish the above. d. Secretary is authorized to construct necessary flood protection measures in the above area.	House Report 3678; 98-616 part I, 98th Congress 2d session.

Table 2. Everglades National Park Authorizations (Continued).

ACTION	DESCRIPTION	NOTES
Extension of Modified Water Delivery Schedules, ENP. Pub. L. No. 100-676, 102 Stat. 4040 s. 40.	Amends the first sentence of Supplemental Appropriations Act of 1984 from Jan. 1, 1989 to Jan. 1, 1992.	
ENP Protection and Expansion Act of 1989. Pub. Law 101-229, 103 Stat. 1946.	Enlarges Park boundary to include approximately 107,600 acres.	

and water resource investigations. The USGS also maintains a network of hydrologic stations for the U.S. water resources data base (Greenhorne and O'Mara, 1989).

Soil Conservation Service. Congress directed the Secretary of Agriculture to establish the Soil Conservation Service (SCS) in 1935 with authority to administer Title 16, Chapter 3B, Soil Conservation (United States Code. Title 16, Section 590e). The Congressional policies administered by the SCS include the control and prevention of soil erosion, preservation of natural resources, provision of flood control, prevention of reservoir impairment, and maintenance of the navigability of rivers and harbors (United States Code. Title 16, Section 590a).

Bureau of Indian Affairs. Congress established the Bureau of Indian Affairs (BIA) within the Department of the Interior in 1832. Headed by an Assistant Secretary for Indian Affairs, the BIA is the lead federal agency in discharging the obligations of the United States to American Indian Tribes and their members. The BIA acts for the federal government in the management of Indian lands and natural resources which are held in federal trust status. The bureau has wide-ranging responsibilities mandated by Congress to assist the Tribes in economic development and in the development of tribal government. It also has the direct responsibility for the education of Indian children and the provision of a variety of social services for tribal members. (Seminole Tribe of Florida, 1990; United States Code. Title 25, Section 13.)

U.S. Army Corps of Engineers. The U.S. Army Corps of Engineers (Corps) is the federal agency in charge of civil works. The Corps constructs and operates surface water related projects and regulates dredging and filling activities in waters in the state (Florida Bar Association, 1988). The Corps cooperates with other federal and state agencies to develop flow regimes to enhance environmental values within the ENP while at the same time meeting flood control and water supply objectives (CH_2MHill, 1989).

Central and Southern Florida Project for Flood Control and Other Purposes. Congress initially authorized the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project) through the Flood Control Act of 1948 (United States Congress, 1948). Various amendments to the Flood Control Act resulted in subsequent authorizations of the Project. The primary purpose of the C&SF Project is to provide a "comprehensive plan for flood protection, water supply, and allied purposes." The originally conceived "allied purposes" of the C&SF Project included preservation of fish and wildlife, navigation (United States Congress, 1949). Through a series of Governing Board resolutions, the District has assumed responsibilities as the local cooperator for the Project. The federal authorizations for the C&SF Project, the District's acceptance of the local cooperator's responsibilities, and a brief description of each appear in **Table 3**. The District's specific duties as local cooperator are summarized in **Figure 1**. (Local cooperator responsibilities for new projects will be in accordance with the accompanying Congressional authorization.)

Table 3. Local Cooperator Responsibilities, Central and Southern Florida Project for Flood Control and Other Purposes.

(Excerpts from H.D. 643 and District Resolution No. 12)

1. Provide all lands, easements and rights of way.
2. Provide cash contributions of a percentage of the estimated construction costs of the federal government.
3. Save and hold harmless the federal government from damages due to the construction and operation of the Project works.
4. Maintain and operate the Project works in accordance with the regulations prescribed by the Corps, except for the following works: St. Lucie Canal, Lake Okeechobee, Caloosahatchee River; and the main spillways to the Water Conservation Areas (S-10, S-11 and S-12).

The Corps designed and built, and Congress has financed, over eighty percent of the cost of the C&SF Project. The District's operation of the C&SF Project as local sponsor is subject to the final control and authority of the Corps pursuant to the Flood Control Acts and Corps regulations. The Corps developed the general design memoranda for C&SF Project structures; sets regulation schedules for Lake Okeechobee, the WCAs, and canals; and supervises daily operation of structures. Moreover, the Corps retains ownership of the S-10, S-11, and S-12 structures, which control movement of water among the WCAs and from the WCAs into the Park. The District operates these structures under contract with the Corps and simply carries out the Corps' orders with respect to their operation.

Waters that contain elevated concentrations of nutrients, which are the subject of this SWIM Plan and of Section 373.4595(2)(a)1 of the SWIM Act, is moved into and out of the EAA and the WCAs and into the Park by operation of the C&SF Project under the supervision of the Corps, pursuant to the purposes for which Congress authorized and funded the C&SF Project.

U.S. Environmental Protection Agency. The U.S. Environmental Protection Agency (EPA) is responsible for the protection of environmental resources subject to regulatory control under United States Code, Title 42, Section 4341. The EPA administers the Clean Water Act. Under section 402 of the CWA, the EPA issues National Pollution Discharge Elimination System (NPDES) permits for point source discharges. Under section 319 of the CWA, EPA has overall responsibility to require states to develop nonpoint source control programs. The EPA reviews DER permits for treatment, disposal and storage of hazardous waste. The EPA also has the authority to prohibit or to restrict discharges of dredged or fill materials in waters of the United States (33 U.S.C. 1344(c)). EPA is also responsible for administering the Resources Conservation and Recovery Act (RCRA) which has some importance for Everglades agricultural interests and is important for water quality considerations in the study area.

4. Indian Tribes

Seminole Tribe of Florida. The Seminole Tribe of Florida is a federally recognized Indian tribe which occupies federal trust lands in five Florida locations, including the Big Cypress, Hollywood, and Brighton reservations, and the Immokalee and Tampa Indian communities. The present total population of the

Table 4. C&SF Project Authorizations.

ACTION	DESCRIPTION	NOTES
Florida Legislature creates Everglades Drainage District, 1905, 1907, 1913.	Powers include: (1) taxation; (2) bond authority; (3) use of funds from land sales to carry on drainage works. By 1928, constructed 6 major canals (Caloosahatchee, Miami, North New River, Hillsboro, West Palm Beach, St. Lucie), and other facilities.	
Florida Legislature creates Okeechobee Flood Control District in 1929.	Responsibilities to include local cooperation for Caloosahatchee River and Lake Okeechobee project.	
Rivers and Harbors Act of July 3, 1930 (Public Law 71-520).	Congress authorizes Caloosahatchee and Lake Okeechobee drainage areas improvement project as recommended in Senate Document No. 115.	Changed levee levels to 31 feet from 34 feet with allowance to raise levee an additional 3 feet. U.S. to construct, and Florida to make cash contributions.
ENP Protection and Expansion Act of 1989, Pub. Law 101-229, 103 Stat. 1946.	Enlarges Park boundary to include approximately 107,600 acres.	
Flood Control Act of June 30, 1948 (Public Law 80-858).	Congress authorizes Phase I of the comprehensive plan for flood protection, water control, and allied purposes contained in House Document No. 643.	Navigation, flood control, allied purposes to benefit. Modified Caloosahatchee River and Lake Okeechobee drainage areas to include Phase I of the plan recommended in House Document 643.
1949 Ch. 25270, Ch. 25420.	Florida Legislature creates Central and Southern Florida Flood Control District (CSFFCD).	CSFFCD absorbs Okeechobee Flood Control District. Liquidation of Everglades Drainage District (EDD). Transfer of EDD facilities to CSFFCD.
Resolution No. 12, August 1, 1949.	CSFFCD assumes full responsibility for compliance with the requirements for local cooperation set forth in House Document No. 643.	Local cooperator responsibilities as defined in Figure 1.
Flood Control Act of September 3, 1954 (Public Law 83-780).	Congress expands the 1948 authorization to include the entire comprehensive improvement plan for flood protection, water control, and allied purposes contained in House Document 643.	
Resolution No. 224, September 15, 1954.	CSFFCD assumes full responsibility for compliance with requirements for local cooperation set forth in the Flood Control Act of 1954.	
Flood Control Act of July 3, 1958 (Public Law 85-500).	Congress adds project elements as recommended in House Document 186 and Senate Document 48.	Additional project elements located on the west side of the Everglades agricultural area and conservation area in Hendry County.
Resolution No. 398, October 9, 1959.	CSFFCD assumes full responsibility for compliance with requirements for local cooperation set forth in the 1958 Act as recommended in H.D. No. 186.	
Flood Control Act of July 14, 1960 (Public Law 86-645).	Congress adds project elements as recommended in Senate Document No. 53.	Additional project elements located in Nicodemus Slough area, Glades County.
Flood Control Act of 1962 (Public Law 87-874).	Congress authorizes modifications of comprehensive plan as recommended in Senate Document Nos. 138, 123, 125, 139 and 146.	Adds projects for West Palm Beach Canal, Boggy Creek, Shingle Creek, Cutler Drainage Area, South Dade County, Reedy Creek Swamp.
Resolution No. 512, 514 April 5, 1963.	CSFFCD assumes full responsibility for compliance with the requirements of local cooperation set forth in the 1962 Act as recommended in Senate Document Nos. 138, 123 125, 139 and 146.	
Flood Control Act of October 27, 1965 (Public Law 89-298).	Congress authorizes modifications of the comprehensive plan for flood protection, water control and allied purposes as recommended in Senate Document No. 20.	Adds project elements in Hendry County (superseding Flood Control Act of July 3, 1958) and Southwest Dade County.
Resolution No. 744, June 9, 1967.	CSFFCD assumes responsibility for compliance with the requirements of local cooperation set forth in the Flood Control Act of 1965 as recommended in Senate Document No. 20.	
Flood Control Act of 1968 (Public Law 90-483).	Congress authorizes modifications of the comprehensive plan for flood protection, water control, and allied purposes as recommended in House Document No. 369.	Adds Martin County and the Water Resources Plan. Provides for conservation and conveyance of additional water supplies for ENP, for agricultural and urban needs, recreation, and other purposes.
Resolution No. 880, October 17, 1969.	CSFFCD assumes responsibility for compliance with the requirements of local cooperation set forth in the Flood Control Act of 1968 as recommended in House Document No. 369.	Local cooperator responsibilities include: (1) cash contributions; (2) construction and maintenance; (3) provide necessary lands; (4) costs of necessary local infrastructure; (5) indemnification of U.S. for construction, operation, and maintenance; (6) prohibit encroachments on carrying capacity of improved channels; (7) operate and maintain works for flood control, navigation, back pumping and delivery of water to ENP, agricultural areas, and urban areas (caveat: no guarantees of delivery); (8) contribute toward recreational development.
River Basins Appropriation Act of June 19, 1970 (Public Law 91-282).	Congress authorizes appropriations for prosecution of the comprehensive plan approved in the Flood Control Act of 1948, as amended. Congress establishes minimum delivery rate from CSFFCD to ENP.	Specifies works to which funding will be allocated, including works to be specified by the ENP plan of improvement for meeting water requirements of the ENP.

Table 4. C&SF Project Authorizations.

ACTION	DESCRIPTION	NOTES
Water Resources, Conservation, Development and Infrastructure Improvement and Rehabilitation Act of 1983. Supplemental Appropriations Act of 1984. Pub. L. No. 98-181, 97 Stat. 1292-1293 (1983).	a. Authorizes the Secretary with concurrence of SFWMD and Director of NPS to modify the schedule for delivery of water from the C&SFP to ENP and to conduct an experimental program for delivery of water to the Park. b. Authorizes Secretary to make modifications in Comprehensive Plan for flood control as needed to restore natural flow of water. c. Secretary is authorized to acquire such lands as are necessary to accomplish the above. d. Secretary is authorized to construct necessary flood protection measures in the above area.	House Report 3678; 98-616 part I, 98th Congress 2d session.
Public Law 99-190, 99 Stat. 1185, Further Continuing Appropriations, 1985.	Joint resolution making further continuing appropriations for fiscal year 1986.	Prohibits use of funds in connection with deer hunting in the Loxahatchee National Wildlife Refuge.
Water Resources Development Act of 1986 (Public Law 99-662).	First major civil works authorization since 1970 Omnibus Water Resources Management and Financing Act.	
Water Resource Development Act of 1988. Pub. Law 100-676, 102 Stat. 4012.	Establishes funding mechanisms for various aspects of water resource development.	
Water Resources Development Act of 1990. Pub. Law 101-640, 104 Stat. 4604.	Provides additional project funding. Includes an environemtnal protection mission, no net loss of wetlands interim goal.	
Energy and Water Development Appropriations Act, 1992. Pub. Law No. 102-4, 105 Stat. 510.	Various appropriations for energy and water development.	

Tribe is estimated at 1,800. The Tribe governs itself under a constitution and bylaws approved by the Secretary of the Interior pursuant to Section 16 of the Indian Reorganization Act, 25 U.S.C., ss. 476. In 1987, the Tribe entered into a settlement agreement with the State of Florida and the SFWMD, resolving certain tribal land claims against the state and the District and providing for the transfer into federal trust of 15 sections of land which had been part of a state reservation established for the Indians in 1931. The state and the District retained certain flowage easements required for water management purposes. The remainder of the Tribe's interests in the state reservation was purchased by the state and the District.

As part of this settlement, the Tribe, the state and the District entered into a Water Rights Compact which applies to all tribal lands except for the tribal holdings in Tampa. Chapter 285, Florida Statutes, ratified the Water Rights Compact between the Seminole Tribe and the District and the State of Florida (Section 285.165 Florida Statutes). Under the Compact, the Tribe has agreed to follow the provisions of substantive Florida water law, with certain exceptions and preferences, and under special procedures which provide for tribal access to the federal courts for the resolution of controversies. The Compact, which applies to the Tribe as a matter of federal law, is the sole source of regulation of water resources on tribal lands.

Miccosukee Tribe of Indians of Florida. The Board of Trustees of the Internal Improvement Trust Fund is authorized to transfer lands to the Miccosukee Indian Tribe (Section 285.061, Florida Statutes). In a 1982 settlement agreement, the state agreed to the transformation of the state reservation in WCA-3 to a federal reservation. Currently, the Tribe leases lands in the WCA for fishing and hunting and other traditional Indian activities. Through a Memorandum of Agreement, the District and the Tribe have obligated themselves to use the utmost good faith and best efforts in structuring and implementing a comprehensive Water Rights Compact governing state/tribal cooperative water management for the future. (South Florida Water Management District, 1987a).

B. DISTRICT-CORPS OF ENGINEERS RELATIONSHIP

1. Construction and Operation.

The District and the USCOE have joint responsibilities for the construction, operation and maintenance of the C&SF Project. As outlined above in the section dealing with the C&SF Project, the USCOE designed and built and Congress has financed over eighty percent of the cost and the District's operation of the facilities as local sponsor is subject to the final control and authority of the USCOE pursuant to the Flood Control Acts and USCOE regulations.

2. Planning.

This section outlines the USCOE planning process (based on Schwartz, 1989, personal communication; USCOE Pamphlet EP 1105-2-10, 1987). The discussion reveals that this process is thorough, complex, and time consuming. An understanding of the complexities of this process is important because of the SWIM plan's potential to trigger a need for future District-USCOE planning efforts which affect the C&SF Project. It is also important to remember that this federal process gives the USCOE (and to some extent other federal agencies) a powerful influence, including veto authority, over some potential programs and projects recommended in this plan if they are found to impact the federally mandated operational criteria of the C&SF Project.

There are several major steps in the planning, design, and implementation of a USCOE civil works project. The subsequent steps may vary based on the nature of the proposal. Procedures for authorized, but never constructed elements of the C&SF Project are different than a proposed project feature that has not been previously authorized. Additionally, a proposal to redesign a completed project feature may be treated like a new element of the project. The following offers an overview of the full procedure for new elements.

The first step in this process involves identification of local water or related land resource problems which require federal assistance to resolve. The next step involves a request for federal assistance. If obtaining federal assistance depends upon a congressional authorization, the District will contact the Florida congressional delegation. Through Public Works Committees, a member of Congress requests study authorization. As identified in **Table 3**, a wide range of congressional authorizations already exist for the C&SF Project. New elements outside the scope of these existing approvals require congressional study authorization.

Upon study authorization by the Public Works Committee, the USCOE' district office begins a two-phase study of the resource problem. The first phase is the development of a reconnaissance report and is funded 100 percent by the federal government. This report, which must be completed within one year, defines resource related problems, identifies potential alternative solutions, appraises federal interest in the potential solutions and identifies a local sponsor willing to cost share the next study phase. If the reconnaissance report determines federal participation in further study is warranted, a feasibility study is initiated.

The feasibility study evaluates potential solutions and the costs and benefits of the alternatives. If this phase results in a determination that there is a federal interest and viable solutions, a Feasibility Report and an Environmental Impact Statement (EIS) are prepared. The Feasibility Report and EIS, which are jointly funded by the USCOE and the local sponsor, go through a review process which includes the District Engineer, Division Engineer, Washington Level Review Center, the Board of Engineers for Rivers and Harbors, the heads of federal agencies, and state government. Public comments are considered at several review stages. The proposed report of the Chief of Engineers and final EIS are sent to heads of federal agencies and governors of affected states for comment. The final EIS is filed with EPA and made available to the public.

This review process results in a final report of the Chief of Engineers which is submitted to the Assistant Secretary of the Army for Civil Works. The Assistant Secretary of the Army for Civil Works submits the report to OMB for comments on the report as it relates to the president's programs. After the review process, the Assistant Secretary submits a final report and recommendation to the Congress.

Following submission of report to Congress, the USCOE continues advanced planning, pending congressional authorization of the project. This process is known as the Pre-construction Engineering and Design (PED) phase. As part of the PED phase, a General Design Memorandum and Detailed Design Memorandum may be prepared.

The congressional authorization process begins with the submittal of the Chief of Engineers' report to the House Committee on Public Works and Transportation and the Senate Committee on Environment and Public Works. After committee hearings are conducted the project is authorized by Congress, usually through the enactment of an omnibus bill, the Water Resources Development Act. Federal funding of the project normally occurs in the annual Energy and Water Development Appropriations Act.

Subsequent to congressional approval, the District and the USCOE discuss matters which relate to land acquisition and the ultimate design of the right of way. Right of way design requires the review and mapping of engineering plans and specifications. In addition, the land acquisition strategies must allow for necessary adjustments to avoid problems such as takings, severances, and relocations, while at the same time staying within the integrity of the original design.

The next phases in the project planning process involve the preparation of plans and specifications, funding, land acquisition, permit acquisition, and actual construction of the project. The USCOE is responsible for the preparation of the contract, plans and specifications, with concurrence from the District. Next, funding must be obtained. Funding has a federal component and a local component. The congressional authorization for the project specifies the percentages of responsibility of the federal and local components. The local sponsor is responsible for obtaining the necessary real estate interests. The methods used by the local sponsor to meet this responsibility include negotiation, acceptance of donations, and eminent domain.

In coordination with the above described activities, the USCOE proceeds to advertise for the contractor, lets the contract, and construction begins. After the USCOE's contractor completes the work, the USCOE tenders the project to the local sponsor for inspection. Subsequent to a favorable inspection, the local sponsor accepts certain responsibility for the project. The District's Governing Board accepts these responsibilities through a Board resolution and at the same time designates the project elements as District works.

The District, as local sponsor for the C&SF Project, has normally accepted the responsibilities of operation and maintenance. The USCOE requires that the District operate and maintain the project works in accordance with USCOE criteria, which are contained in the Operation and Maintenance Manual, Water Control Plans, and Water Control Manuals. The USCOE has retained the responsibilities for the operation and maintenance of C&SF Project facilities which consist of the St. Lucie Canal, the Okeechobee Waterway, the Caloosahatchee River, C-111 Canal, and the S-10, S-11, and S-12 structures, which discharge directly into ENP. With regard to the operation of the S-10, S-11, and S-12 structures, the District acts as an independent contractor of the USCOE rather than as the local sponsor. The USCOE is responsible for the maintenance of these structures.

C. RESOURCE AUTHORIZATIONS AND JURISDICTIONS

The following sections identify federal and state laws that substantially impact the Everglades SWIM planning effort. The discussion also includes coverage of other legal commitments of the District, mainly contractual obligations.

The discussion focuses on the law which relates to the interests of water supply, flood control, water quality, and fish and wildlife. These interests often conflict with one another and should be balanced in order to achieve a harmonized and legally sound approach to the Everglades SWIM plan. However, the District lacks final authority to reconcile conflicts among water supply, flood control, and other purposes of the Project, including water quality. That can only be done by the United States which has yet to provide any guidance on such a reconciliation.

1. Water Supply

Federal. The legal requirements for water supply are governed primarily by the federal law which resulted in the authorizations for the Central and Southern Florida Flood Control Project. House Document Nos. 643 and 369 establish the major elements of the Project's water supply features.

House Document No. 643 establishes Lake Okeechobee and the Water Conservation Areas as the water supply source for Everglades National Park, Florida's lower east coast, and for the Everglades Agricultural Area (United States Congress, 1949). House Document No. 369 provided the precedent for water deliveries to ENP and recommended several federal works to improve the water deliveries to the ENP (United States Congress, 1968).

In 1983, Congress passed the Water Resources, Conservation, Development and Infrastructure Improvement and Rehabilitation Act ("Fascell Bill")(United States Congress, 1983a). This law suspended the ENP water delivery schedule to allow for experimentation in control of flow to ENP (United States Congress, 1983b).

State. The State is responsible for allocating water supply releases from project storage, except where specified by federal law. The Corps considers the authorized water supply purposed in determining the regulation schedules and operating criteria for the C&SF Project. The main body of law which regulates water supply on the state and regional level appears in Chapter 373, Florida Statutes. Part II provides for a consumptive water use permit program which has been implemented by the District (Section 373.216 - 373.245, Florida Statutes; Rule 40E - 20, Florida Administrative Code). Chapter 373, Florida Statutes, provides for planning for water use and water supply as part of a state-wide comprehensive planning effort (Section 373.036, Florida Statutes). Chapter 373, Florida Statutes, authorizes the District to issue water shortage orders when water supplies are reduced due to drought or overuse (Section 373.246, Florida Statutes).

Indian Tribes. Indian water rights are governed by a water rights compact. The compacts are superior to any other federal or state laws on the subject of water supply. A water rights compact is in effect between the District and the Seminole Indian Tribe (South Florida Water Management District, 1987b). The District and the Miccosukee Indian Tribe are currently negotiating a revised water rights compact.

2. Flood Control.

Federal. On the federal level, flood control is regulated through the Congressional authorizations for the C&SF Project (see **Table 3**). Under these authorizations, Lake Okeechobee provides flood control for the Everglades Agricultural Area; the Water Conservation Areas provide flood protection for the Everglades Agricultural Area and the Lower East Coast. Specific regulation schedules have been established for both Lake Okeechobee and the Water Conservation Areas to ensure that the system of levees remains intact, to provide hurricane protection, and to comply with the federal operation schedules.

State. On the state level, flood control and surface water management is regulated through Part IV of Chapter 373, Florida Statutes. Part IV requires that adequate flood protection be provided by all nonexempt construction or alteration of dams, impoundments, reservoirs, and other works which can affect the water resources of the state. The District implemented Part IV, Chapters 17-40, and 17-25, and Rule 40E-6, Florida Administrative Code through the adoption of the rules and criteria which govern the construction or alteration of surface water management systems (Rule 40E - 4, Florida Administrative Code). Flood control, along with water quality and environmental considerations, make up the main evaluative criteria for surface water management systems.

Indian Tribes. Indian water rights are governed by a water rights compact. The compacts are superior to any other federal or state laws on the subject of flood control. A water rights compact is in effect between the District and the Seminole Indian Tribe (South Florida Water Management District, 1987b). The District and the Miccosukee Indian Tribe are currently negotiating a water rights compact (South Florida Water Management District, 1987a).

3. Water Quality

Federal.

Recommendations for the Central and Southern Florida Project for Flood Control and other Purposes: House Document Nos. 643, 186, and 369. House Document Nos. 643, 186, and 369 contain recommendations for the C&SF Project, adopted through a series of Congressional authorizations (see **Table 3**).

House Document No. 643 establishes the major elements of the Project (United States Congress, 1949). Congress authorized Phase I in 1948 and by 1958, had completely authorized the C&SF Project. House Document No. 643 focuses essentially upon flood control and water supply. It's coverage of water quality is limited to providing relief from the effects of flooding upon septic and sewer systems.

Congress authorized the recommendations contained in House Document No. 186 in 1958 (United States Congress, 1958). This authorization added C&SF Project elements on the west side of the Everglades Agricultural Area and the WCAs in Hendry County. House Document No. 186 provides very little coverage of water quality.

In 1969, Congress authorized the recommendations contained in House Document No. 369 for additional Project works and provided for the conservation and conveyance of additional water supplies for agriculture, urban needs, and for Everglades National Park (United States Congress, 1969). Although House Document No. 369 does not make specific recommendations on water quality, it recognized water quality as a prime objective of the operation of the Project. House Document No. 369 states that, to the extent practicable, operation methods be employed which evaluate and minimize concentrations of pesticides, herbicides, and nutrients. This Document also provides for the incorporation of water quality control into Project operations based upon the results of continuing studies.

Federal Water Pollution Control Act (Clean Water Act). The Federal Water Pollution Control Act was originally enacted by Congress in 1948 (United States Congress, 1948). Since 1948, the Act has gone through substantial amendments. The Act is commonly referred to as the Clean Water Act and has as its objective to restore and maintain the chemical, physical, and biological integrity of the nation's waters (United States Code, Title 33 Section 1257a). The Act establishes two major regulatory schemes which consist of water quality standards and effluent limitations. Prior to 1987, the Clean Water Act focused primarily upon the regulation of effluent from sewage treatment facilities and other discharges, commonly referred to as "point-source" pollution (American Jurisprudence, 1981). In 1987, Congress adopted significant amendments to the Act (United States Congress, 1987). These amendments authorized a state-federal program to provide federal support and cost-sharing for state efforts to control diffuse sources of pollutants, commonly referred to as "non-point source" pollution. The 1987 amendments also strengthened existing programs for the improvement of water quality in lakes (Environmental Reporter, 1987).

Other provisions of the Act direct the EPA to solve pollution problems in estuaries. The EPA is also responsible for the regulation of stormwater discharges and effluent limitations under the Act.

National Environmental Policy Act. Congress enacted the National Environmental Policy Act (NEPA) in 1969 (United States Code. Title 42, Section 4321). The objectives of NEPA are to declare a national environmental policy and to establish a council to review national policies and environmental problems. The purposes of NEPA are to encourage harmony between man and the environment, to promote efforts which will prevent or eliminate damage to the environment, and to enrich the understanding of ecological systems and natural resources. NEPA establishes a federal regulatory framework for development activities and includes within its scope, state or private developments in which there is federal participation. NEPA requires the integration of environmental considerations in the decision making process. The documentation of this consideration is contained in a written assessment. Projects having significant effects on the quality of the environment must be supported by a detailed Environmental Impact Statement (see also Florida Bar Association, 1988). An EIS is required for "major Federal actions significantly affecting the quality of the human environment . . . ." 42 USC 4332(2)(C). An "environmental assessment" must be prepared by federal agencies for proposals that are not categorically exempt from the EIS requirement unless the agency has already decided to prepare an EIS [40 CFR 1501.3(a) and 1501.4(a) (1989)]. In very general terms, an environmental assessment is intended to guide an agency's decision on whether an EIS is required or to document a finding of no significant impact. 40 CFR 1501.4(b) and (c) and 1508.9. NEPA imposes no obligations on state agencies.

Resource Conservation and Recovery Act. The Resource Conservation and Recovery Act (RCRA) mandates a comprehensive program for the management of waste materials, placing its primary emphasis upon hazardous waste (United States Code, Title 42. Section 6901). The hazardous waste coverage of RCRA includes: 1) identification and listing of wastes; 2) establishment of standards that apply to generators, transporters, owners, and operators of hazardous waste and hazardous waste sites; 3) establishment of a permit system for the treatment, storage, or disposal of hazardous waste; and 4) the establishment of state hazardous waste programs, inspections, and federal enforcement (Florida Bar Association, 1988).

State Law.

Water Resources Act of 1972. The Water Resources Act of 1972 (Ch. 373, F.S.), authorizes the water management districts to consider water quality as one of the elements involved with the management of water and related resources. The Act also establishes the Legislature's intent that the water management districts promote water quality through environmental enhancement and to promote the water quality aspects of the state water policy. In 1987 the Florida Legislature enacted the Surface Water Improvement and Management (SWIM) Act (Ch. 87[-]97, Fla. Laws). This law requires the water management districts to create and implement plans for the protection and restoration of designated priority water bodies. In 1989, stormwater regulation was incorporated into Part IV regulation of surface water management by water management districts (Florida Legislature, 1989).

Pollution Control. Chapter 403 of the Florida Statutes establishes a comprehensive state pollution control program. The Florida Department of Environmental Regulation has responsibilities for the regulation of the point source water quality aspects of the pollution control program. The DER's regulatory authority includes point source discharges to surface waters and ground waters, dredge and fill activities, the classification of water bodies, and adoption of state water quality standards.

Outstanding National Resource Waters. Rule amendments recently promulgated by DER designate a new water quality classification of "Outstanding National Resource Waters" (ONRW). The rule amends the state water quality standards by imposing an anti-degradation standard for designated water bodies, upon confirmation by the legislature (Fla. Admin. Code 17-3.041(9) and 17-4.242). The Everglades National Park and Biscayne National Park are water bodies that have been included in the rule's designations of ONRWs (Fla. Admin. Code 17-3041(18)(a)2). However, the designation is not effective, according to the regulation, "until the Florida legislature enacts legislation specifically authorizing protection and maintenance of Outstanding National Resource Waters to the extent required by the federal Environmental Protection Agency pursuant to 40 CFR 131.12." (Fla. Admin. Code 17-3.041(18)(b)). Proposed legislation to accomplish this designation is pending (House Bill 947). The baseline for defining the existing ambient water quality in the Park, if designated as an ONRW, will be the period from March 1, 1976 to March 1, 1981 (Fla. Admin. Code 17-3.041(18)(d).

Executive Order No. 88-25. Executive Order No. 88-25 was issued by Governor Bob Martinez in an effort to reaffirm the importance of the Everglades system to the State of Florida (State of Florida, 1988). The Executive Order directs governmental agencies, including the District, to prevent continuing threats to the Everglades system. One element of the Executive Order's action plan is to require strict scrutiny of proposed development in the Everglades. The Executive Order also limits the purposes for which public lands located in the Everglades may be developed to the purposes of water and other natural resource management. The text of the Executive Order appears as an appendix, in Volume IV of this report.

Majory Stoneman Douglas Everglades Protection Act of 1991. The Marjory Stoneman Douglas Everglades Protection Act (MSD) requires the District to adopt a SWIM Plan for the Protection of the Everglades Protection Area which would include strategies in addition to those required under SWIM. This includes strategies for meeting water quality standards and to restore the Everglades hydroperiod. The District and the USCOE must apply for permits for their discharges into and within the Everglades Protection Area. For the District, both programs require development of ambient water quality concentration levels and interim levels to meet applicable state water quality standards to the maximum extent possible. Schedules, monitoring, research and funding and land acquisition programs are also required.

Other

Senate Report No. 91-895. In 1970, the Committee on Public Works issued this report, which concerned appropriations for several projects, including the C&SF Project. The report includes provisions relating to water supply for the ENP and points out that consideration of the quality of water to be delivered to the ENP is important for ecosystem preservation. The report also advises the USCOE and the National Park Service to agree on measures "to assure that the water delivered to the park is of sufficient purity to prevent ecological damage or deterioration of the park's environment.

Everglades National Park Water Quality Monitoring Agreement. In 1984, the District, the U.S. Army Corps of Engineers, and the Everglades National Park updated a 1979 memorandum of agreement to protect the quality of water entering Everglades National Park (SFWMD, 1984). The memorandum of agreement provides for water quality monitoring for specified water quality parameters and provides that the more stringent water quality criteria of federal, state, and local government shall continue to apply to the water deliveries.

Holey Land/Rotenberger Tract Memorandum of Understanding. In 1983, a Memorandum of Understanding was entered into by the DER, the Board of Trustees of the Internal Improvement Trust Fund, the FGFWFC, and the District (SFWMD, 1983). The Agreement establishes a process for the implementation of a plan to restore the Everglades values associated with the Holey Land/Rotenberger Tract. The Agreement also provides for the establishment of water regulation schedules which 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. The agreement provides for hydroperiod improvements in Holey Land and WCA-3. Details of the agreement and the expected environmental benefits can be found in the Holey Land discussions in Section VI of this volume.

S.N. Knight Tract Agreements.. In 1989, the Board of Trustees of the Internal Improvement Trust Fund and the District entered into an agreement for the use of the state-owned farm land previously leased to S.N. Knight and Sons (SFWMD, 1989). In the same year, the District entered into an agreement with S.N. Knight & Sons, Inc. (State of Florida, 1989b). These agreements provide for the gradual conversion of the tract from an agricultural use to a water treatment use. The agreements provide for the diversion of agricultural runoff from the Everglades Agricultural Area (EAA) to the property for treatment by a biological filter (the Everglades Nutrient Removal Project) prior to discharge of the waters into the WCAs.

4. Fish and Wildlife

Federal

Fish and Wildlife Coordination Act. This Act, passed by Congress in 1958, established federal policy of giving wildlife conservation equal consideration with other features of water resource development programs. The Act also encourages planning, development, maintenance and coordination of wildlife conservation and rehabilitation through interagency cooperation and water control consultation. Estimations of wildlife benefits or losses associated with water control or use projects, are required by the Act, to be included in reports to Congress which recommend authorization of such projects.

Endangered Species Act. On the federal level, the Endangered Species Act provides an important method of legal protection for fish and wildlife resources (United States Code, Title 16, Section 1531 *et seq*). The Act requires federal agencies to utilize their authorities in furtherance of the purposes of the Act by carrying out programs for the conservation of endangered and threatened species listed pursuant to the Act (16 USC 1536(a)(l)). The Act also requires each federal agency to insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any such species or result in the destruction or adverse modification of officially designated critical habitat of such species (16 USC 1536(a)(2)). The Act declares a Congressional policy that federal agencies shall cooperate with state and local agencies to resolve water resource issues in concert with conservation of endangered species (16 USC 1531(c)(2)). The Act directs federal and state agencies to cooperate with one another to resolve water resource issues in concert with the conservation of endangered species.

House Document Nos. 643 and 369. Other coverage of fish and wildlife is contained in the Congressional authorizations for the C&SF Project. House Document No. 643 provides that the comprehensive plan for flood control and water supply also is intended to preserve and protect fish and wildlife resources as an allied purpose (United States Congress, 1949). The modifications to the C&SF Project contained in House Document No. 369, which altered water deliveries to ENP, also recognize the importance of preservation and protection of fish and wildlife resources, consistent with operation of the overall project (United States Congress, 1968).

State

Florida Endangered and Threatened Species Act. This Act (Ch. 372.072 F.S.) adopted in 1977 establishes a state policy to conserve and manage Florida's diverse fish and wildlife resources. The Act requires more stringent measures to conserve and manage species which have been identified as endangered or threatened by the DNR, FGFWFC, and by the federal government. The Act provides for a public education program and the transmission to the Legislature of an annual report including a revised and updated plan for management and conservation of endangered and threatened species and of statewide policies pertaining to protection of endangered species (Section 372.072(4) and (5), Florida Statutes).

Other

U.S. Fish and Wildlife Service Agreement for WCA-1. In 1951, the District and the USFWS entered into a 50-year cooperative and license agreement for all of the lands located within WCA-1. Under the terms of the cooperative and license agreement, the Service manages WCA-1 as a wildlife management area to promote the conservation of fish, game, and wildlife, and for recreational development. The cooperative and license agreement provides that maintenance of wildlife habitat in WCA-1 is subject to the primary purpose of use of the land for flood control and water retention purposes (Central and Southern Florida Flood Control District, 1962).

Florida Game and Fresh Water Fish Commission Agreements for WCA-2 and WCA-3. In 1952, the District granted a 25-year license to the FGFWFC for the purposes of wildlife and fish preservation, protection, propagation, and for the promotion of recreation. The license is renewable on an automatic basis. The FGFWFC's activities are subject to, and must be consistent with, the flood control, water retention, and other requirements of the USCOE (Central and Southern Florida Flood Control District, 1964).

D. REFERENCES

American Jurisprudence Second, Volume 61A, Section 129, 141[-]156 (1981).

CH_2MHill, 1989. Technical Memorandum No. 9, January 3, 1989.

Central and Southern Florida Flood Control District, 1962. Cooperative and License Agreement between the Central and Southern Florida Flood Control District and the U.S. Fish and Wildlife Service for Management of Water Conservation Area No. 1, dated June 8, 1951, and as amended on August 7, 1953, December 15, 1959, and July 23, 1962, respectively.

Central and Southern Florida Flood Control District, 1964. Cooperative and License Agreement between the Central and Southern Florida Flood Control District and the Game and Fresh Water Fish Commission, dated January 18, 1952, and as addended January 15, 1964.

Environmental Reporter, 1987. Bureau of National Affairs, The Clean Water Act Amendments of 1987, Environment Reporter, Vol. 18, No. 19 p.1-5 (1987).

Florida Administrative Weekly, 1989a. Florida Administrative Weekly, Volume Number 7, pages 741, 743, February 17, 1989.

Florida Administrative Weekly, 1989b. Volume 15, Number 7, page 1982, May 12, 1989.

Florida Bar Association, 1988. Environmental and Land Use Law Section, Florida Bar, Florida Environmental and Land Use Law, Vol. I, 1-9 to 1-10 (1988).

Florida Bar Association, 1988. Environmental and Land Use Law Section, Florida Bar, Florida Environmental and Land Use Law, Vol. II, Ch. 1-21 (1988).

Florida Bar Association, 1988a. Environmental and Land Use Law Section, Florida Bar, Florida Environmental and Land Use Law, Vol. II, Ch. 1-1 (1988).

Florida Bar Association, 1988b. Environmental and Land Use Law Section, Florida Bar, Florida Environmental and Land Use Law, Vol I, Ch. 1-7 to 1-11 (1988).

Greenhorne and O'Mara, 1989. Greenhorne & O'Mara, Subtask B.1, B.2, B.4, February 1989.

Quincey, Irene Kennedy, 1989. SFWMD Deputy District Counsel. Personal communication, June, 1989.

Schwartz, T. 1989, District Real Estate Counsel. Personal communication, May 1989.

South Florida Water Management District, 1983. Contract No. 66/0408BBBMA, Memorandum of Agreement between the Florida Department of Environmental Regulation (DER) and the Board of Trustees of the Internal Improvement Trust Fund (TIITF) and the South Florida Water Management District (SFWMD) and the Florida Game and Fresh Water Fish Commission (FGFWFC) Concerning the Holey Land and Rotenberger Project, dated May 13, 1983.

South Florida Water Management District, 1984. Memorandum of Agreement among the Army Corps of Engineers, the South Florida Water Management District and the National Park Service for the Purpose of Protecting the Quality of Water Entering Everglades National Park, dated February 10, 1984.

South Florida Water Management District, 1987a. Memorandum of Agreement between the Miccosukee Tribe of Indians of Florida and the South Florida Water Management District, dated June 10, 1987.

South Florida Water Management District, 1987b. Water Rights Compact Among the Seminole Tribe of Florida and the South Florida Water Management District, October 29, 1987.

South Florida Water Management District, 1988. Identification of Priority Water Bodies within the South Florida Water Management District. South Florida Water Management District, West Palm Beach, Florida Special Publication, February, 1988.

South Florida Water Management District, 1989a. Contract No. C89[-]0103, Board of Trustees of the Internal Improvement Trust Fund of the State of Florida Management Agreement, March 30, 1989.

South Florida Water Management District, 1989. Board of Trustees of the Internal Improvement Trust Fund of the State of Florida Agreement: Management Agreement No, 3665 between the Board of Trustees of the

Internal Improvement Trust Fund of the State of Florida, Division of State Lands, State of Florida Department of Natural Resources and the SFWMD, March, 1989.

State of Florida, 1913. Florida Laws, 6456.

State of Florida, 1929. Florida Laws, 13711.

State of Florida, 1929. Florida Laws, Ch. 72[-]299, Fla. Laws.

State of Florida, 1934. Florida Statutes. Chapter 48, section 816. Everglades National Park Act. (codified at United Sates Code. Title 16 Section 410).

State of Florida, 1935. 1935 Laws of Florida, 17131.

State of Florida, 1949. Florida Laws, 25211, 25420.

State of Florida, 1972. Florida Laws, Ch 72[-]299 Florida Statutes. The Water Resources Act.

State of Florida, 1976. Florida Laws, Ch. 75-125, 76-243.

State of Florida, 1977. Section 372.072, Florida Statutes Florida Endangered and Threatened Species Act.

State of Florida, 1987. Chapter 87-97 Florida Laws; codified at Sections 373.451 - 373.4595 Florida Statutes. Later amended (State of Florida, 1989a).

State of Florida, 1988. Governors Office. Executive Order No. 88[-]25.

State of Florida, 1989a. S.B. 484, 1989 Florida Legislature.

United States Code. Title 16. Section 590e, 1935a.

United States Code. Title 16. Section 590a, 1935b.

United States Code. Title 25. Section 1, based on Act July 9, 1832, Chapter 174, section 1, 4 Stat. 564.

United States Code. Title 25. Section 2.

United States Code. Title 25. Section 13.

United States Code. Title 33. Section 1251 *et seq.* (includes History; Ancillary Laws and Directives). Clean Water Act. 1948.

United States Code. Title 42. Section 4341.

United States Code. Title 42, Section 4321 *et seq.* National Environmental Policy Act (NEPA). 1969.

United States Congress, 1948a. Flood Control Act of June 30, 1948, Pub. L. No. 80-858.

United States Congress, 1948b. Act of June 30, 1948, ch. 758, 62 Stat. 1155 as codified at United States Code. Title 233 Section 1251 *et seq.*

United States Congress, 1949. H.R. Doc. No. 643, 80th Cong., 2d Sess.

United States Congress, 1958. Fish and Wildlife Coordination Act. Pub. L. No. 85-624.

United States Congress, 1958. H.R. Doc. No. 186, 85th Cong., 1st Sess.

United States Congress, 1968. H.R. Doc. No.369, 90th Cong., 2d Sess.

United States Congress, 1970. S. Report No. 91-895, 91st Cong. 2d Sess.

United States Congress, 1983a. Water Resources, Conservation, Development and Infrastructure Improvement and Rehabilitation Act of 1983, Supplemental Appropriations Act of 1984, Pub. L. No. 98-181, 97 Stat. 1292-1293 (1983); amended by Pub. L. No. 100-676, 102 Stat. 4040 section 40 (1984) (Extension of Modified Water Delivery Schedules, Everglades National Park).

United States Congress, 1983b. H.R. Rep. No. 3678, 98[-]616 part I, 98th Cong., 2d Sess. (1983).

United States Congress, 1985. Further Continuing Appropriations. Pub. Law 99-190, 99 Stat. 1185, 99th Cong., 1st Sess.

United States Congress, 1987. Water Quality Act of 1987, Pub. L. 100[-]4, 100th Cong. 198.

United States Congress, 1989. The Everglades National Park Expansion Act. Public Law No. 101-229. Senate 724, House of Representatives 1727, Amended June 21, 1989.

United States Congress, 1990. Water Resources Development Act of 1990. Pub. Law 101-640, 104 Stat. 4604.

United States Congress, 1991. Energy and Water Development Appropriations Act, 1992. Pub. Law No. 102-104, 105 Stat. 510, 102d Congress.

This Page Intentionally Left Blank

II. SYSTEM DESCRIPTION

This section of the Everglades SWIM Plan provides a system wide description and summary of some essential features of the Everglades region, including physical features, hydrology, plant and animal communities and economics. Emphasis is placed on resources and problems that occur throughout the system. These topics are also discussed, in detail, in subsequent sections of this Plan as they apply to individual basins within the planning area.

A. INTRODUCTION AND OVERVIEW.

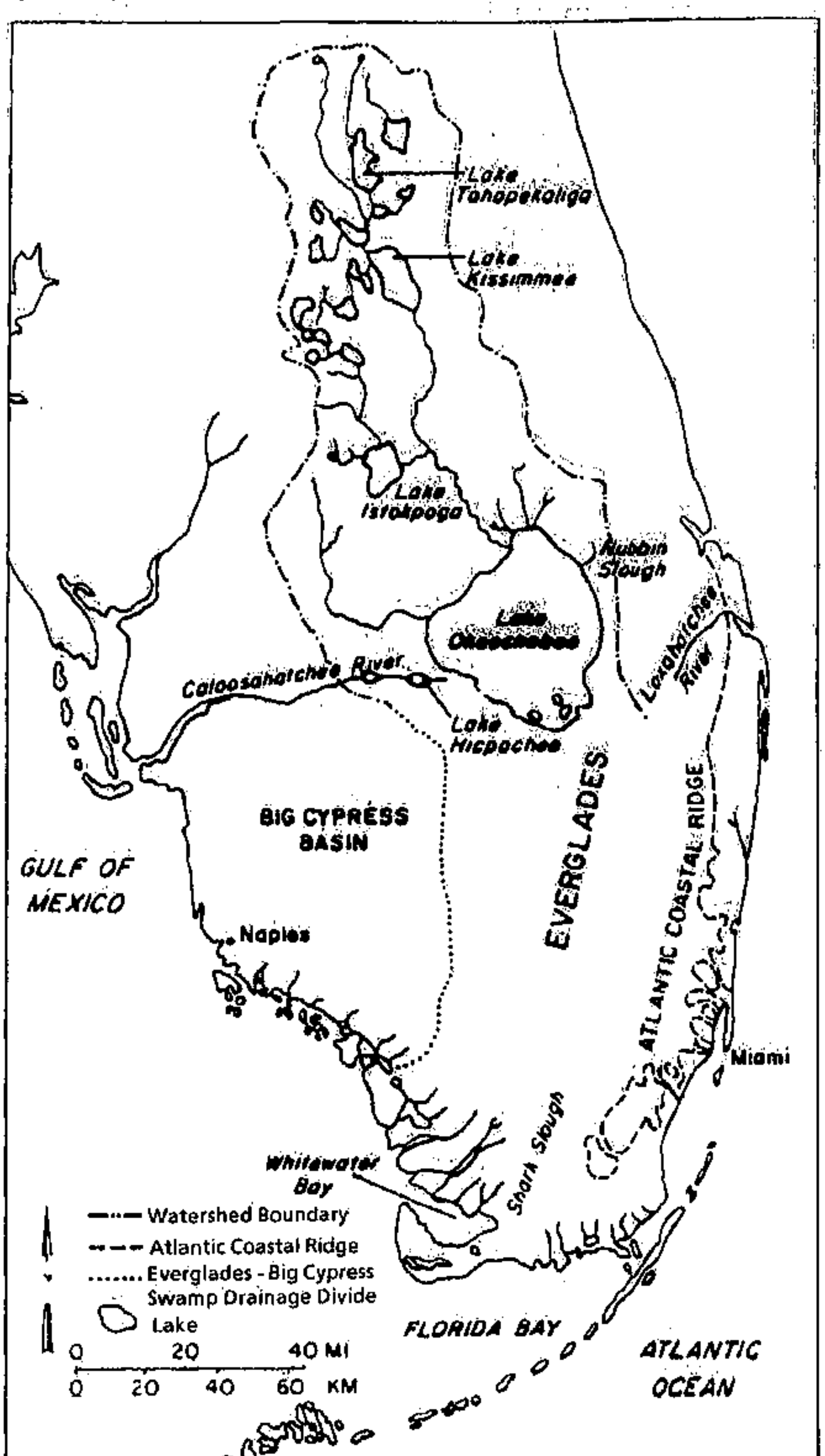
The Everglades have been described as a vast, shallow sawgrass marsh, dotted with tree islands and interspersed with wet prairies and aquatic sloughs that historically covered most of southeastern Florida (Davis, 1943a). The Everglades is the southern end of the Kissimmee Lake Okeechobee Everglades (KLOE) system that includes most of south and central Florida below the City of Orlando (**Figure 1**). The original Everglades were dense, seemingly impenetrable wetlands, extending over an area approximately 40 miles (64 km) wide by 100 miles (160 km) long, from the south shore of Lake Okeechobee to the mangrove estuaries of Florida Bay. Large segments of original Everglades have been separated from the natural system by canals and levees. Today, much of the Everglades supports a variety of land uses, ranging from intensively managed agriculture in the north to rapidly spreading urban areas east of the three Water Conservation Areas (WCAs).

Everglades habitats are divided into two general regions: 1) the WCAs, which represent northern Everglades habitat, include the majority of intact natural Everglades and are located within the central portion of the study area; and 2) the southern Everglades habitat, which occurs in Everglades National Park (ENP) and in the southern third of WCA3. ENP, located at the southern terminus of the KLOE system, has international ecological significance as a designated World Heritage Site. As a whole, the Everglades represents one of the most striking freshwater ecosystems in the country (Fernald and Patten, 1984).

Water is a crucial and fundamental element of the Everglades ecosystem, important not only because of its direct effect on wetland biota, but also because of its influence on ecosystem processes. The quantity, timing, distribution and quality of freshwater entering the Everglades, more than any other environmental variables, influence the capacity of the marsh to support unique vegetation, fish and wildlife resources (Beard, 1938; Davis, 1943a; Schomer and Drew, 1982).

Solutions proposed to alleviate the environmental problems of the Everglades, must include an understanding of how the physical features and hydrologic processes of the Everglades interact to affect water movement, quantity and quality. The environmental health of the Everglades depends on frost, fire, the quantity, spatial and temporal distribution, and quality of freshwater in the system. During this century an extensive water management system has been constructed for flood control which allowed agricultural and urban development in and near the Everglades. The physical features and operational policies of the water management system are linked to the natural features and hydrology of the region. Most environmental problems in the Everglades have occurred as a result of drainage and development of these wetlands.

Figure 1. The Everglades as Part of the Kissimmee-Lake Okeechobee-Everglades (KLOE) Watershed.



Source: Jarosewich and Wagner, 1985

Section I reviews the physical features, hydrology,and water management, biological resources and economics in the Everglades from a system-wide perspective. Section I is divided into six subsections: (A) Introduction and Overview; (B) Description of the Planning Area; (C) Physical Features; (D) Hydrology; (E) Major Plant Communities; (F) Threatened and Endangered Species, Species of Special Interest or Concern; and (G) Regional Economics. Subsection B defines the Everglades SWIM planning area. Subsection C describes the natural and man-made features of the planning area. Subsection D summarizes the region's physical features and hydrology, including current water management practices, impacts of development, and future climatic changes. Subsection E discusses the nature and distribution of major plant communities within the region, including their ecology and importance within the Everglades ecosystem and the dependence of these communities on water management. Subsection F provides a discussion of threatened and endangered plant and animal species within the planning area and the dependence of these species on appropriate natural resource management practices. Subsection G describes the importance of the Everglades system as a component of the regional economy.

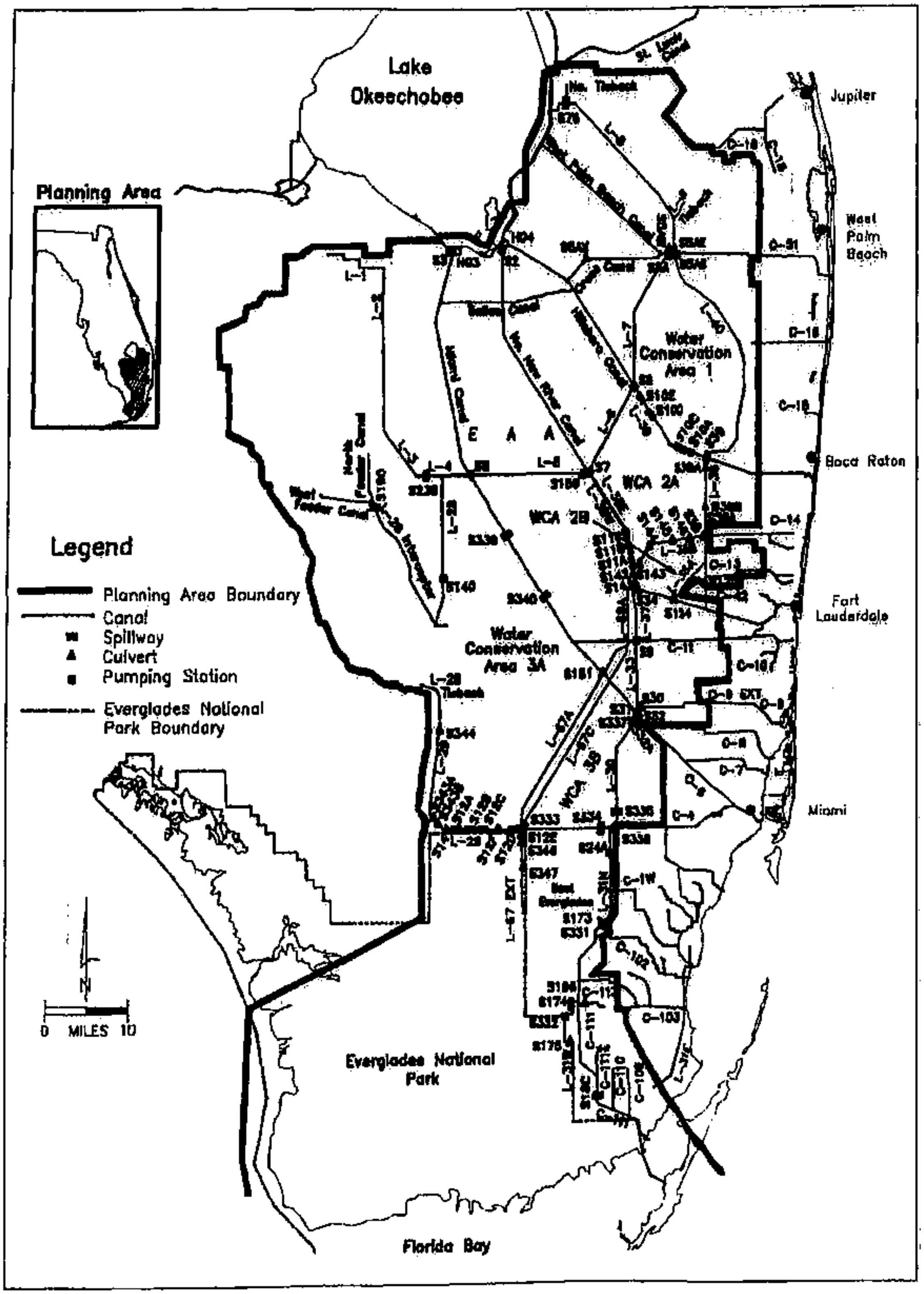
B. PLANNING AREA

The Everglades represent the largest freshwater system in Florida and is the southernmost component of the KLOE ecosystem **(Figure 1)**. The Everglades SWIM planning area covers 5,778 square miles (14,965 km^2) in Palm Beach, Broward, Dade, Monroe, Collier, and Hendry counties **(Figure 2)**. The water bodies primarily addressed in this plan (Water Conservation Areas 1, 2 and 3 and Everglades National Park), cover approximately 3,533 sq. mi. (9,151 km^2) of native Everglades habitat located in portions of Dade, Broward, Palm Beach, Collier, Hendry and Monroe counties. Other areas are included in the planning area based on their hydrologic relationships to the primary water bodies. These areas include the Everglades Agricultural Area (EAA), eastern coastal drainage basins (i.e., the C-51 and C-13 basins and the Acme Improvement District), western drainage basins (i.e., the L-3 canal, Feeder Canal, and L-28 Gap basins), the East Everglades Area (EEA), and the C-111 basin.

The Everglades basin is a large, flat, shallow depression extending from the present day location of the Cities of Clewiston and Pahokee in a great arc 40 to 50 miles wide and over 100 miles long to the Gulf of Mexico. Boundaries of the Everglades SWIM planning area include: to the north, the area bounded by Lake Okeechobee, C-44 and C-18 basins; to the east, boundaries are generally defined by a line that runs one mile east of the eastern levee which runs north and south through Palm Beach, Broward and Dade counties, including tributary basins which currently (or potentially) drain into the Everglades basin; to the west, by the Immokalee Rise, Big Cypress Spur and Big Cypress Preserve drainage basin (Davis, 1943a; White, 1970); and to the south by the southern boundary of Everglades National Park, which incorporates most of Florida Bay **(Figure 2)**.

Most of the original Everglades was a sawgrass marsh with occasional sloughs, swamps, and hammocks (Davis, 1943a). Large parts of the northern and eastern Everglades have been drained and converted to urban or agricultural land uses. Other large areas in the central Everglades have been impounded by levees and are now affected by water management activities.

Figure 2. Everglades SWIM Planning Area.



C. PHYSICAL FEATURES OF THE EVERGLADES BASIN

1. Topography.

The Everglades area is topographically flat with elevations generally less than 20 feet (6 m) National Geodetic Vertical Datum (NGVD). The ground surface generally slopes from north to south with an average gradient of 0.15 feet /mile (2.8 cm/km)(Parker *et al.*, 1955). The highest ground elevations occur in the northern Everglades at 17 feet (5.2 m) NGVD. The lowest elevations occur in the southern Everglades at 0.3 to 1.0 feet (10 to 30 cm) NGVD. A water level is the distance from the water's surface to some reference elevation or "datum." In the District, all water levels are relative to NGVD. Water levels are measured in feet and are sometimes referred to as "stage."

2. Geology and Soils.

Structure and Geologic Setting. The Floridan Plateau underlies the state of Florida as a projection of the North American continent that separates the Gulf of Mexico from the Atlantic Ocean. This plateau underlies the Everglades, Florida Bay, and the Florida Keys, including the present Florida land mass, and all of the submerged area surrounding the state to the edge of the continental shelf at approximately the 300 ft (90 m) depth contour. In the Gulf, the plateau slopes gently to the west and extends up to 150 mi (240 km) offshore. On the south and east, the plateau drops off sharply into the Bahamas Trench and the Straits of Florida (Antoine and Harding, 1963).

Nearly 20,000 feet (6,000 m) of predominantly shallow marine carbonate sediments underlie South Florida. These sediments range in age from Jurassic to Holocene, and have accumulated over a period of 136 million years above a Triassic-Jurassic basement of volcanic rocks (Antoine & Harding, 1963). The rock floor beneath the Florida peninsula is a truncated surface of various igneous and sedimentary rocks of chiefly Precambrian and early Paleozoic age.

Stratigraphy. The formations that play a major role in the hydrologic cycle of the Everglades are Miocene or or younger in age and include the upper portion of the Hawthorn Group, Tamiami Formation, Fort Thompson Formation, Anastasia Formation and Miami Limestone, as well as undifferentiated surface soils and sediments. All of these lithologic units combine to form the Surficial Aquifer System in the Everglades region (Fish, 1988).

<u>Hawthorn Group</u>. Scott and Knapp (1988) divided the Hawthorn into two major lithologic units in South Florida: an upper unit of predominantly clastic material and a lower unit composed principally of carbonates. These two units are separated by a major unconformity. The Hawthorn may vary in thickness from 550 to 800 feet (170 to 240 m) within the Everglades basin. It is composed of a heterogeneous mixture of green clay (calcareous and dolomitic), silt, phosphate, carbonates (limestone to dolomite), and fine quartz sand (Fish, 1988; Knapp *et al.*, 1986). Although a few zones within this sequence may qualify as minor aquifers, Hawthorn sediments are relatively impermeable. The Hawthorn is important to the Everglades because it forms a barrier to vertical migration of water into or out of the Surficial Aquifer System (**Figure 3**).

Figure 3. Generalized Stratigraphic Units and Hydrogeologic Properties, South Florida (modified from Schroeder *et al.*, 1958 and Gleason *et al.*, 1984.)

Aquifer System	Period	Epoch	Formation	Characteristics
BISCAYNE AQUIFER SYSTEM	Quaternary	Holocene	Terrace Deposits - Okeechobee Muck - Everglades Peat - Loxahatchee Peat - Lake Flirt	Quartz Sands Unconsolidated freshwater sediments consisting of peat, clay, marls, sandy muck, calcitic mud. Permeable.
		Pleistocene	Pamlico Sand	Permeable quartz sand, white to black, very fine to coarse. Covers large area underlain by Miami Oolite and Anastasia Formation.
			Miami Limestone	Limestone, oolitic with a lower Bryozoan Layer. Permeable
			Anastasia Formation	Coquina, sand, calcareous sandstone, sandy limestone, and shell marl. probably composed of deposits equivalent in age to marine members of Fort Thompson Formation. Permeable.
			Key Largo Limestone	Cavernous coralline reef rock. Very Permeable.
			Fort Thompson Formation	Sandy and marly clay, silt, and shell beds. Generally low permeability.
	Tertiary	Pliocene	Caloosahatchee Marl	Sandy and marly clay, silt, and shell beds. Generally low permeability
		Miocene	Tamiami Formation	White and greenish- gray clayey marl. silty shelly sand, and shell marl locally hardened to limestone. Upper unit is highly permeable, lower unit is of low permeability.
HAWTHORN AQUIFER SYSTEM			Hawthorn Formation	Sandy, silty with "green clay" or marl. Generally impermeable, however interstratified with sand and sandy pebble lenses.

Tamiami Formation. The Tamiami Formation consists of a number of different lithologies, all Miocene to Pliocene in age. The top of the Tamiami is characterized by low permeability, poorly hardened limestones, dolosilts, and calcareous sands. Below this semi-confining unit is a sandy, fossiliferous limestone which is the primary water producer of the Lower Tamiami Aquifer. This limestone grades downward into the coarse Miocene clastics of the Upper Hawthorn Group (Knapp *et al.*, 1986).

Surficial Sequence. During the Pleistocene and Holocene (most recent) epochs, a series of glacial periods, or ice ages, brought about drastic changes in sea level. As a result of these sea level fluctuations, the Florida peninsula was alternately covered and uncovered by a shallow sea. Prior to the initial Pleistocene glacial melt, approximately 60,000 years before the present, sea level was nearly 270 ft (83 m) above its present level. Dry land on the Florida peninsula was then restricted to a few small islands along the central Florida ridge in what is now Polk County, and an archipelago in the vicinity of Trail Ridge in Jacksonville (Cooke, 1945). At the peak of the last glacial period, sea level was bout 400 feet (135 m) below its present level.

The last glacial melt began about 17,000 years before present (Fairbridge, 1974). Subsequent sea level fluctuations, accompanied by seafloor expansion, gradually created the present configuration of the Florida Peninsula. As the sea that covering the Florida Plateau retreated, the submerged oolitic ridge, now known as the Atlantic Coastal Ridge, emerged as dry land. Tidal channels were washed through the unstable oolitic ridge, connecting the shallow sea covering what is now the Everglades with the Atlantic Ocean. These channels form the parallel cut and grooves known today as the Transverse Glades (Hoffmeister, 1974).

The three limestone formations that comprise the surficial sequence of the Everglades Basin were deposited in one of these shallow Pleistocene seas, during what is known as the Sangamon Interglacial (Parker and Cooke, 1944). These formations are the Fort Thompson, the Anastasia, and the Miami Oolite. The Fort Thompson Formation underlies the northern half of the basin, extending south into Dade County. It is characterized by marine and freshwater marls, limestone and sandstone at a depth of approximately 165 ft (50.3 m) (Parker and Hoy, 1943; Hoffmeister, 1974).

The Anastasia Formation is the main surficial sequence beneath the southern Everglades. It varies in composition from calcareous sandstone to biogenic limestone and coquina rock. Where exposed in the west, the Anastasia Formation is marked by facies containing bryozoan fossil assemblages. This bryozoan facies dips to the east, where it is covered by oolitic rock, a variety of limestone composed of minute spherical grains of calcium carbonate (Hoffmeister, 1974).

The Miami Oolite formation extends from north of Miami southwestward to Homestead and westward into the ENP. Maximum elevation for this formation occurs at 23 feet (7.0 m) above mean sea level (Hoffmeister *et al.*, 1967) in the Coconut Grove area. From there the formation dips to the west, where it disappears under the wetlands of the Everglades. The oolitic rock of the Miami is soft and friable in nature, except where it has been hardened by exposure to the atmosphere. The surface of the formation is honeycombed with holes and fissures. These features, the result of chemical weathering, facilitate the rapid infiltration of rainfall to ground water (Hoffmeister, 1974)

Holocene Sediments and Soils. The primary soils of the Everglades region are Holocene sediments. The organic sediments have been classified according to the principal identifiable plant species components by Allison and Dachnowski-Stokes (1932), Davis (1943a), Gallatin and Henderson (1943), and Craighead (1971), and include the specific names of Okeechobee muck, Okeelanta peaty-muck, Everglades peat, Loxahatchee peat (Soil Conservation Service, 1958).

The organic soils (peats and mucks) have accumulated in a layer of up to 18 feet (5.5 m) thick in the northern Everglades (Stephens and Johnson, 1951) where bedrock elevations are the lowest, thinning to about 3 feet (1 m) or less in the southern Everglades. Gleason *et al.* (1984) dated the oldest peats in the Everglades to approximately 5,000 years before the present. The other dominant soil type in the Everglades is calcitic mud. Sites that contain this surficial sediment in the shallow, peripheral marshes of the southern Everglades have shorter periods of inundation than sites underlain by peats (Gunderson and Loftus, 1989, in press). These calcitic muds have been given various names, including the Lake Flirt Marl, Perrine Marl (SCS, 1958) and *Helisoma* marl (Craighead, 1971).

Pure marl is white to cream colored, becoming darker gray and brown with increasing organic content. The mud is biogenically produced by blue green algae that precipitate calcium carbonate originally dissolved from the parent limestone bedrock (Gleason, 1972). It may also contain remains of freshwater snail shells such as *Helisoma*.

3. Aquifer Systems.

Introduction. Unlike geologic formations, which are defined on the basis of similar lithology or fossil assemblages, hydrogeologic formations (aquifers) are defined by their ability to store and transmit water. The hydrogeology of South Florida is extremely diverse. It includes aquifers which are confined (in which groundwater is under greater than atmospheric pressure, and isolated from vertical recharge), semi-confined (having some vertical recharge), and unconfined (groundwater is at atmospheric pressure and water levels correspond to the water table).

Three major aquifer systems have been recognized in the Everglades SWIM planning area; the Floridan, the Intermediate (Hawthorn), and the Surficial. The Floridan, a confined (artesian) aquifer, though regionally very important is unpotable within the planning area. Overlying the Floridan is the Intermediate Aquifer System, located within the Hawthorn Formation. This System has only limited potential as an aquifer, but serves as a confining unit for the top of the Floridan and the base of the Surficial Aquifer System (Fish, 1988; Knapp *et al.*, 1986). Additional information on aquifers located within the study area can be found in the following publications: Parker and Cooke (1944), Parker (1952), Parker *et al.* (1955), Schroeder *et al.* (1958), McCoy (1962; 1972), Klein (1972), Klein and Hull (1978), the Center for Wetlands (1979), Parker (1982), and Kreitman and Wedderburn (1984).

Surficial Aquifer System. The Surficial Aquifer System is the source of most of the potable water in the Everglades SWIM plan area. It comprises all of the materials from the top of the intermediate confining beds to the water table. Since the water table rises above land surface over large areas of the interior, and historically much of South Florida was annually flooded, the vadose zone and zone of tension saturated sediments may also be included within the bounds of the Surficial

Aquifer System. These materials consist of cavity-riddled limestone and sandstone, sand, shell and clayey sand with minor amounts of silt or clay, and range in age from Miocene to Holocene (Causaras, 1985). Jarosewich and Wagner (1985) divided these lithologies into two distinct zones: an upper zone of permeable limestones and clastics, and a more heterogeneous lower zone of low permeability sands interbedded with permeable sands, limestones, and shelly marls. Due to large differences in permeability between adjacent materials, some areas may exhibit semi-confined aquifer characteristics when stressed by drought or large withdrawals. However, the hydraulic head is closely related to the water table. As a result, the permeable upper zone and the permeable beds in the lower zone are believed to be hydraulically interconnected, and are considered to comprise one single Surficial Aquifer System.

Sediments within the Surficial Aquifer System exhibit a wide range of permeability, and may be divided locally into one or more aquifers separated by semi-confining layers (Fish, 1988). Of these aquifers, only the Biscayne is formally named.

Klein and Hull (1978) describe the Biscayne as a highly permeable wedge-shaped unconfined aquifer that is more than 200 feet (60 m) thick on the coast and tapers to a thin edge 35 to 40 miles (55 to 65 km) inland in the Everglades. The geologic and hydrologic characteristics of the Biscayne Aquifer have been extensively described by Parker *et al.* (1955), Schroeder *et al.* (1958), and Klein and Hull (1978). It is composed of limestone, sandstone and sand. These lithologies comprise all or part of the following geologic formations: 1) the Tamiami Formation, 2) the Fort Thompson Formation, 3) the Anastasia Formation, 4) the Miami Oolite, 4) the Pamlico Formation. The Tamiami Formation forms the base of the aquifer. In most of Dade county the Fort Thompson and the Anastasia Formations comprise the upper and major portion of the aquifer, with the Miami Oolite cropping out at the surface over large areas of the ENP. It is the high permeability of the oolitic limestone that permits rapid infiltration of rainfall and facilitates quick recharge of the aquifer.

The Biscayne Aquifer is the primary source of drinking water for all municipal water systems south of Palm Beach County. Because the Biscayne is highly permeable and allows rapid infiltration of rainfall, it is highly vulnerable to contamination from surface sources. Since this aquifer is the only source of drinking water for a large and heavily populated portion of southeast Florida, the U.S. Environmental Protection Agency (EPA) has designated the Biscayne Aquifer as the "sole source aquifer." This designation, provided by the Safe Drinking Water Act of 1974 (PL 93-03523), requires studies to determine that federally financed projects will not contaminate designated aquifers. Because of past contamination problems in Dade, Broward, and Palm Beach Counties, these counties have instituted wellfield protection programs. According to Klein and Hull (1978), the water quality of the Biscayne Aquifer may be affected by color from high organic soils, the mineral and chemical composition of the aquifer, local land uses which affect runoff quality, physical and chemical composition of rainfall, saltwater intrusion, chemical reactions between water and rocks in the aquifer, and potential pollution sources such as underground storage tanks and landfills.

D. HYDROLOGIC FEATURES

1. Introduction.

The first five parts of this section consider the relationships and relative importance of the component processes of Everglades hydrology as part of the "hydrologic cycle", including the effects of climate, geology and topography. The effects of agricultural, residential, and urban development are addressed under part 6 entitled, Current Water Management and its Impacts on Hydrology.

The description of hydrologic and related features within the Everglades system encompasses the hydrologic cycle, surface and groundwater interactions, natural hydrology and the current regional water management system. Historic hydrology has been altered to a great degree and the Everglades have in turn been affected by compartmentalization, altered hydroperiods, overdrainage of some areas, increased fire frequency and water quality changes. Conversely, inclusion of large areas of the remaining Everglades within the boundaries of the C&SF Project has to a large extent, protected the ecosystem from further development and encroachment. The current regional water management system is now required to provide flood control and water supply for the developed areas of south Florida as well as meet the needs of the natural systems of the remaining Everglades.

Prior to development, the study area was characterized by low-lying, flooded lands that were not suited for agricultural, industrial, or residential uses. Water management activities in this region have occurred primarily to provide drainage, flood protection and water supply for agriculture and urban land development. The current implementation of these activities, the Central and Southern Florida Project for Flood Control and other Purposes (C&SF Project) is one of the largest and most extensive water management projects in the world (see also Planning Document).

Two key concepts are important when considering the interaction between the hydrological and the biological systems of the Everglades:

A. The biological system developed over thousands of years in response to the natural hydrological system.

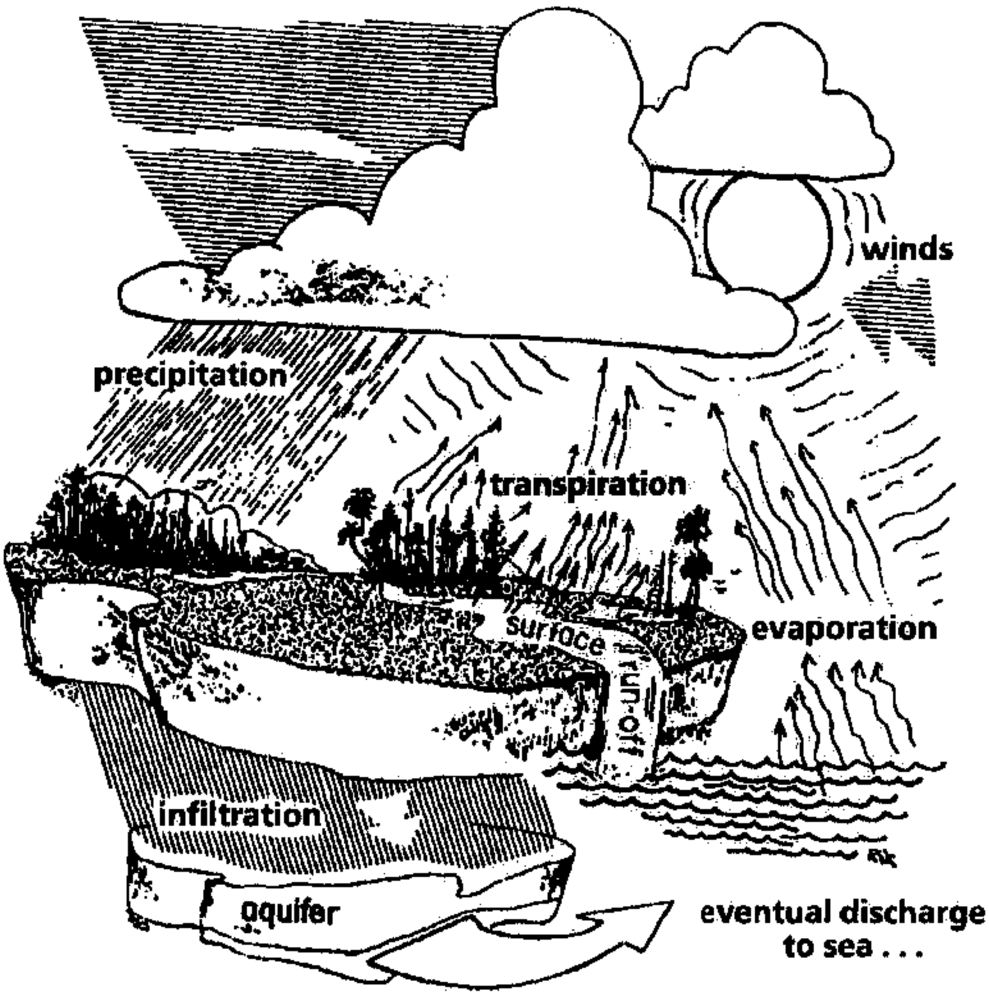
B. The variability and diversity of the biological systems are tied to the natural variability of the hydrologic system.

2. The Hydrologic Cycle.

Components of the Hydrologic Cycle. The interaction of climate, geologic cycle, and topography with surface water is known as the hydrologic cycle (**Figure 4**). The hydrologic cycle is the primary factor influencing the natural and developed areas of South Florida and its millions of human inhabitants. The processes that comprise the hydrologic cycle are rainfall, evaporation, outflows to the ocean, and surface and groundwater storages. Water vapor in the atmosphere condenses to fall as rain. Rainwater is stored for indefinite periods as surface and groundwater and eventually is returned to the atmosphere as vapor by evaporation and transpiration (loss by plants).

The hydrologic cycle on a global scale is a closed system. The total amount of water available to the world is essentially constant and water is simply stored in

Figure 4. The Hydrologic Cycle



different forms--as a gas (water vapor), a solid (ice), or a liquid (water as we think of it). Water cycles between each of these forms as rainfall or other precipitation, water vapor, surface water, ground water, or water in the oceans. Water is also stored as ice, glaciers, and polar ice caps. Water stored as ice is important when understanding the total amount of water available to the world and how water is periodically made available or isolated during periods of sea level change. Sea level changes are particularly important because these are the processes that formed the Everglades. In addition, future global warming may cause sea level changes that will result in significant changes to the south Florida coastal zone.

The Everglades Hydrologic Cycle. The main processes in the Everglades hydrologic cycle are rainfall, evaporation, transpiration, outflows to the ocean, and surface and groundwater storages. Evaporation and transpiration are usually considered together as "evapotranspiration." Of these, rainfall is the only natural contributor to surface and groundwater storages, and evapotranspiration and outflows to the ocean are the only natural loss mechanisms. Since the Everglades is not a closed system, flow across its boundaries should be considered as an important component of a "water balance." Flow across the Everglades boundary consists of both surface water and groundwater. Inflows and outflows from the Everglades are generally much less than rainfall and evapotranspiration.

Water is stored by soils for periods as groundwater.–The relationships between precipitation and available water within a drainage basin are determined by the physiography, vegetation, surficial geology, and topography of the drainage basin (Fetter, 1980). For any given period of time, the difference between the amount of rainfall and inflows and the amount of evapotranspiration and outflows is equal to the change in the amounts of surface and groundwater storages. In general, the changes in surface and groundwater storages on an annual basis are small, although they can be large between the dry season and the wet season.

The Everglades system evolved under hydrologic conditions where availability of water (i.e. water in storage) varied from season to season and year to year. Rainfall over South Florida exhibits considerable variability between seasonal and annual amount, and in areal distribution. Since rainfall is the only contributor to surface and groundwater storage, the variability in amount and distribution of rainfall contributes to differences in the amount and distribution of storage. Although the evapotranspiration loss from storage is a large part of annual rainfall, it is much less variable than rainfall. The evapotranspiration rate is strongly affected by vegetation type, but it exhibits similar seasonal trends from year to year (Shih, 1988).

Everglades ecosystems depend on a certain degree of variation in rainfall and the amount of surface water for their continued existence. For example, the rainfall for Everglades National Park averaged 53 inches (135 cm) a year for the period from 1941 through 1985. Annual rainfall was greater than 67 inches (170 cm) about 10 percent of the time and greater than 80 inches (203 cm) only one percent of the time.

Water Management. The amount of stored water is of critical importance to natural and developed areas of South Florida. Available water storage capacity determines how runoff from rainfall is managed. Excessive rainfall events can result in a) flow into the regional canal system and eventual discharge to tidewater, b) retention of water locally by soils, or natural wetland areas or c) movement into groundwater. If it is not possible for water to move into these storage areas it remains above ground level. Except in marshes and wetlands, this surface retention of excess water is considered flooding. For example, when surface storage is already at capacity, flooding may occur because there is no available room for more water to be stored. When groundwater and surface water storages are less than capacity, water can move in to fill the available space. When there is little water in storage, drought conditions may occur if rainfall is low. Because of the good hydraulic connection between surface water and groundwater, regulating canal water levels is an effective means to regulate groundwater levels.

3. Surface and Ground Water Levels.

Surface Water. Because the Everglades is flat, the relative water surface elevations may be independent of ground surface elevations. When discussing water movement in this region, it is important to consider topography and the location of rainfall, water management, and man-made features such as roads, levees, and canals that affect the movement of water. In every case, the relative water surface elevations must be measured to determine the direction of flow.

Water Levels. A water level is the distance from the water's surface to some reference elevation or "datum". In the Everglades Planning Area all water levels are relative to the National Geodetic Vertical Datum (NGVD). Differences in water levels determine the rate and direction of water movement. Flow is always from the highest to the lowest water level and in general the rate increases as the difference in levels increases. Water surface potential is a numerical value that is related to downward gravitational force and the amount of energy required to hold water at any height above sea level. The difference in water surface levels results in water running from the higher level to a lower level.

Drainage Basins. The drainage basin of a stream is all the land that contributes runoff to the stream or its tributaries upstream of a given point, such as the mouth of the stream. If rain falls over a large enough area, some of the runoff from that storm will likely enter one stream and some of it will enter another stream. It is said that these streams "drain" different basins, that they are in different "drainage basins". The boundary between the basins is termed a "drainage divide" or "hydrologic divide" (Cooper and Lane, 1987).

Because of the flat topography in the Everglades, it is very easy for man to alter natural drainage patterns. Structures such as roads, levees, and railways often form the divides between basins. Where such features are absent, basin boundaries may vary with the location of rainfall and operation of water control structures. Because existing drainage patterns may be altered by the construction or removal of man-made divides, their use in sensitive areas must be carefully planned and controlled

Hydroperiod. Hydroperiod refers to the duration and depth of surface water that covers an area. There are two ways to extend hydroperiod in any given location, (1) Induce and extend sheet flow by adding water from upstream for longer periods of time, and (2) increase the water depth sufficiently so that the forces of evaporation, transpiration, and overland flow require a longer period of time to remove all of the surface water from the marsh.

Everglades marshes are essentially aquatic systems. The presence of surface water, at certain depths and for certain periods of time, is essential to the overall health of the marshes and their associated aquatic animals. These marshes are especially productive for insects, small fishes, crayfish, freshwater shrimp, snails and other organisms that form the basis of the food chain for higher organisms such as wading birds, snail kites and other raptors, and the phenomenal sport and pan fisheries. Equally important, are the seasonal and annual fluctuations of water levels that alter the hydroperiod within various portions of these marshes. Hydroperiod is a generic term and does not imply that the same water conditions should be applied to each area of marsh at the same time each year. It is very important to avoid having the same hydroperiod in all marshes at the same time, or repeating the same hydroperiod year after year. Fluctuations in hydroperiods from year to year are important to maintain the broad diversity of Everglades plant and animal communities.

Effects of Geology The primary geological feature that controls regional hydrology is the permeability of underlying rock. Groundwater, surface water, and water management are all affected. In areas of high permeability, rainfall easily seeps into the underlying rock, but it also may return quickly to canals and streams and augment water levels in the canals and make flood control and land drainage difficult. In areas of low permeability, water moves into underlying rock less easily, but moves more slowly through the rock and provides a residual flow to canals and streams during dry periods. In some rock strata, water may travel considerable distances before re-emerging at the surface as springs or as seepage to canals or streams.

Groundwater. The water table, or phreatic surface, forms the upper surface of an unconfined aquifer. The water table is defined as the surface of atmospheric pressure and is the level at which water stands in a well that penetrates into the aquifer. The shape of the water table determines the distribution of flow within the aquifer. Undulations in the water table correspond to changes in storage within the aquifer. Any factor that affects the shape of the water table and therefore the direction and magnitude of flow in the aquifer (i.e. recharge and discharge areas, pumpage from wells, and permeability) also affects storage.

Groundwater, like surface water, runs down hill from highest to lowest elevation (potential). The shape of the water table will tend to mimic the shape of the land surface above it. In most areas, a general picture of the flow patterns in an unconfined aquifer can be approximated from a topographic map. In the flat topography of the Everglades, this is not always possible. Ground water surface elevations must be directly measured to determine flow direction.

4. Climate and Weather Patterns.

The hydrology of South Florida is strongly affected by its climate, rainfall and weather patterns. This subsection discusses the relative importance of these components of the hydrologic cycle, as they relate to water management of the region. The climate of South Florida has been classified as humid subtropical by Bradley (1972) and tropical savanna by Hela (1952). The Everglades have been classified as tropical rainy using the Koppen classifications and as a subtropical moist forest and a transition between tropical and temperate forest types (Rose and Rosendahl, 1978; Dohrenwend, 1977). These classifications have been applied due to the relatively high rainfall and warm temperatures (Dohrenwend, 1977).

The Everglades has a generally subtropical climate, characterized by long, hot, humid and wet summers followed by mild, dry winters. The wet season, extends from May to October, while the dry season, occurs from November to April (Thomas, 1974). The wet season is characterized by high humidity, intense solar radiation, and unstable atmospheric conditions that result in frequent local thunderstorms, often accompanied by intense rainfall of short duration. Severe tropical storms can also occur during the wet season. Large amounts of rain can fall over localized areas in a short period of time and can result in extended periods of flooding.

The dry season is characterized by mild, dry weather. Frontal storms dominate the weather during the dry season often bringing cool, sometimes freezing temperatures, and rainfall of moderate amount and low intensity. Severe weather can accompany some fronts, bringing thunderstorms, tornadoes, and large amounts of rainfall. Thunderstorms that are not associated with fronts are possible in the dry season, but are relatively infrequent compared to the wet season.

Temperature. The region's temperature regime is determined primarily by proximity to the equator and marine influence (Thomas, 1974). Temperature conditions strongly affect rates of water loss by evaporation and transpiration (Parker *et al.*, 1955). Mean annual temperature for the Everglades ranges from 72 F (22 C) in the northern Everglades to 76 F (24 C) in the south (Thomas, 1974). Mean monthly air temperatures range from a low of 63 F (17 C) in January to a high of 85 F (29 C) (Thomas, 1970). Infrequently, freezing temperatures and frost occur when arctic air masses follow winter cold fronts into the area.

Evapotranspiration. Evapotranspiration (ET), the combined water loss due to transpiration and evaporation, is a major element of South Florida's hydrologic cycle. Average evapotranspiration within the Everglades ranges from 70 to 95 percent of rainfall and in dry years can exceed rainfall in volume (Klein *et al.*, 1975). Evapotranspiration is affected by temperature, solar radiation, wind speed, relative humidity, and transpiration during plant growth. Temperature is generally regarded as the most important factor. Minimum ET rates occur during the winter months (January and December) and increase to maximum rates during the spring months (April and May). ET rates remain high throughout the summer due to high temperatures, high transpiration rates during plant growth, saturated ground conditions and high water levels in wetlands. During dry periods potential evapotranspiration may be greater than actual evapotranspiration. Typical actual average annual evapotranspiration ranges from 40 to 45 inches (100 to 115 cm) with a maximum amount of 60 inches (152cm) (Parker *et al.*, 1955).

Rainfall. On the average, south Florida receives about 53 inches (135 cm) of rain annually, 75 percent of which falls in the wet season (Shih, 1983). During the dry season, precipitation is governed by large-scale (synoptic) winter weather fronts which pass through the region roughly every seven days (Bradley, 1972). Rainfall from these fronts exhibits a more uniform distribution across the Everglades as compared to rainfall derived from the highly variable convection-type thundershowers that occur during the wet season.

Regionally, in south Florida, the east coast, from Homestead to Pompano Beach, generally receives the greatest amount of rainfall,while the Florida Keys and areas south of Lake Okeechobee, southwest Collier County and an area east of Fort Meyers generally receive the least annual rainfall (Klein *et al.*, 1975). Rainfall distributions over the Everglades area follow a bimodal pattern with two peaks occurring, one in May or June and the other in September or October (Thomas, 1974). Since records have been kept, annual rainfall in the Everglades Planning Area has ranged from a low of 37 inches (94 cm) in 1961 to a high of 106 inches (269 cm) in 1947. Typically annual values vary from 40 to 65 inches (102 to 165 cm) with a mean annual rainfall over the Everglades of 51 inches (130 cm) (MacVicar and Lin, 1984). Within the Everglades Planning Area the greatest average annual rainfalls occurs in the EAA and in Everglades National Park. The lowest average annual rainfall occurs in WCA-3A (MacVicar, 1983; Sculley, 1986).

In the wet season, convective showers (thunderstorms) occur almost daily, and their distribution across the study area is largely dependent on sea breeze circulation. Short-duration, high intensity thundershowers are related to cyclic land-breeze convection patterns resulting in midday to late afternoon shower activity. Convective storms exhibit larger differences in precipitation from station to station as compared to winter frontal (synoptic) storms (Bradley, 1972; Woodley *et al*, 1974). Woodley (1970) estimates that, due to natural variability, rainfall generated from a single cumulonimbus cloud in south Florida can range from 200 to 2,000 acre-ft (244,000 to 2,440,000 m^3).

Wind. Winds are persistent year round, but on average, are strongest in the late winter or early spring (March). During the wet season, the prevailing winds are easterly. In the dry season wind direction is variable. Evapotranspiration rates increase with wind speed and therefore wind has an effect on regional hydrology. Wind movement is greatest during the winter when rainfall is usually lowest (Parker et al., 1955). Wind action during the winter exacerbates the drying of marshes and causes increased water demands for agricultural irrigation. Very strong winds associated with hurricanes probably do not affect evapotranspiration losses, but they are an important physical process shaping the Everglades and Florida Bay. High winds and associated wave action can redistribute such physical features as barrier islands, inlets, channels and sand shoals and disrupt established plant and animal communities such as coral reefs, seagrass beds and mangroves.

Extreme Storm Events. Hurricanes, tropical cyclones which generate winds in excess of 74 miles per hour, are recurrent events in south Florida and are important physical processes in the regional ecology (Craighead and Gilbert, 1962). South Florida and the Everglades region have been struck by more hurricanes and tropical storms than any other equally sized area in the United States (Gentry, 1974). The Everglades region is exposed to Atlantic, Gulf, and Caribbean generated hurricanes. Hurricanes strike most frequently during August, September and October with a return frequency of about every three years (Gentry, 1984). Destruction occurs from storm surges, wind, tornadoes, and rainfall (flooding). The hurricanes of 1926, 1928, 1935, 1947, 1960, 1962, and 1965 caused loss of life and/or major damage to the region that led to additional water management and drainage efforts in the Everglades basin.

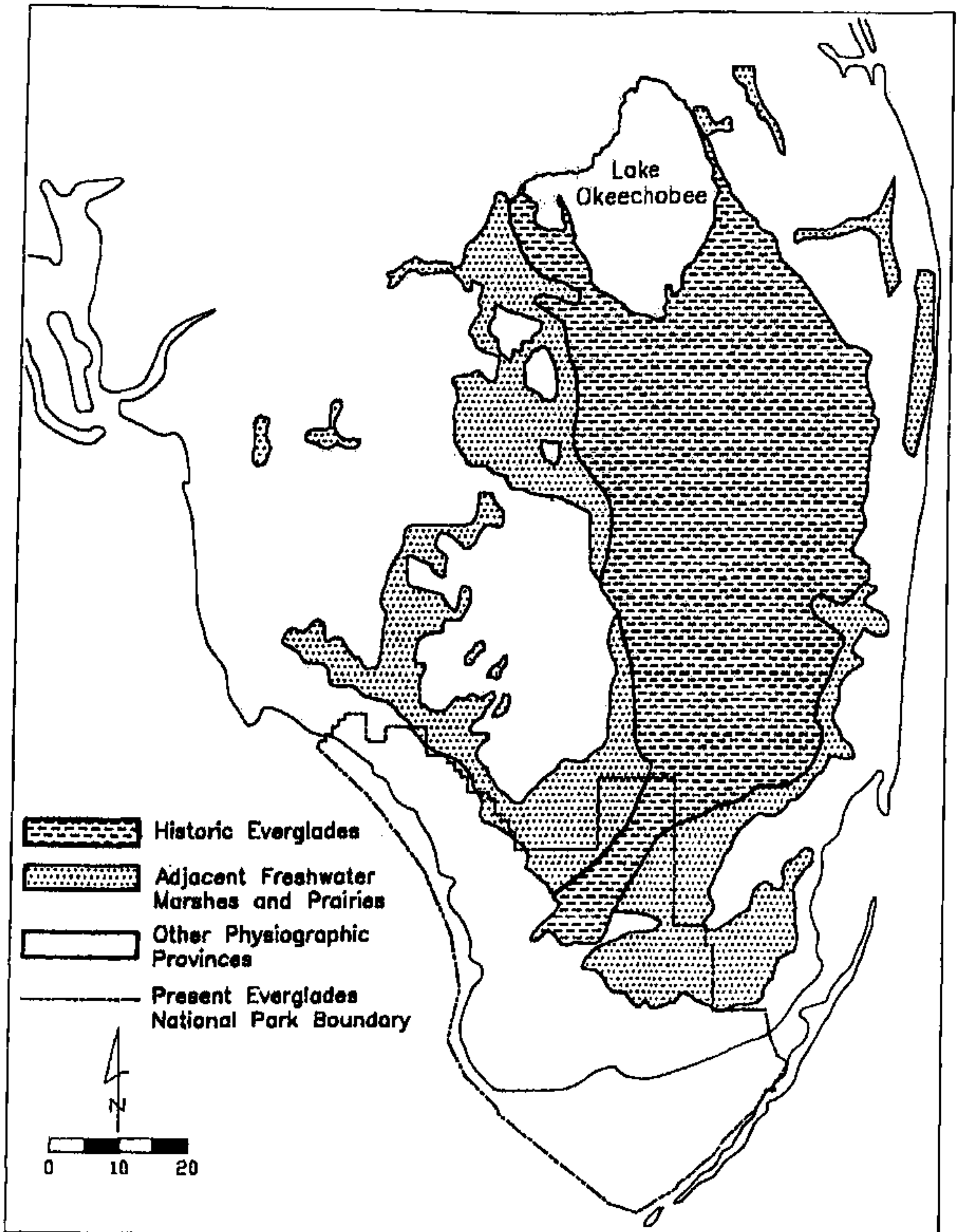
5. Historic Hydrologic Conditions.

Pre-Drainage Hydrology. Everglades wetlands began their formation on bare limestone bedrock approximately 5,500 years ago and by the end of the late 19th century extended over an area of approximately 3,900 sq. mi. (10,000 km^2) covering the majority of south Florida (**Figure 5**). The pre-drainage Everglades region extended south from Lake Okeechobee approximately 90 miles (145 km) to the southern coast at Florida Bay and the Ten Thousand Island region (Davis, 1943a). The Everglades is best described as a depression in the limestone of this region that has filled with organic matter and sedimentary deposits (Parker and Hoy, 1943; Parker, 1974). This system is bordered on the east by the Atlantic coastal ridge and on the west by the Immokalee rise (Parker and Hoy, 1943; Harlem, 1979; Davis, 1943a). These features formed a partial barrier for movement of freshwater to tidewater. The southern outlets of the system were Biscayne Bay, Florida Bay, and the Gulf of Mexico (**Figure 6**).

Prior to drainage, large portions of the KLOE system were inundated each year (Davis, 1943a; Parker, 1984). Heavy rainfall caused the northern portion of the Everglades to flood when Lake Okeechobee overflowed its southern rim. Overflow of the lake occurred primarily at two locations when lake levels reached 14.5 ft (4m) msl (Parker, 1984). The entire southern shore, about 32 miles (50 km) long, flooded the upper glades (the present day EAA) when lake levels exceeded 18 ft (5 m) msl (Parker, 1984). These waters continued to flow south as the 'River of Grass' slowly moving through the sawgrass marsh extending across an area approximately 40 miles (65 km) wide. Water in this system was in constant flux exchanging with the atmosphere by evapotranspiration, rainfall and subsurface movement into and out of the Aquifer (Davis, 1943a; Parker *et al.*, 1955; Wagner and Rosendahl, 1987). Water from the Everglades discharged into tidewater (coastal estuarine mangrove) areas of south Biscayne Bay, Florida Bay, and the Ten Thousand Islands.

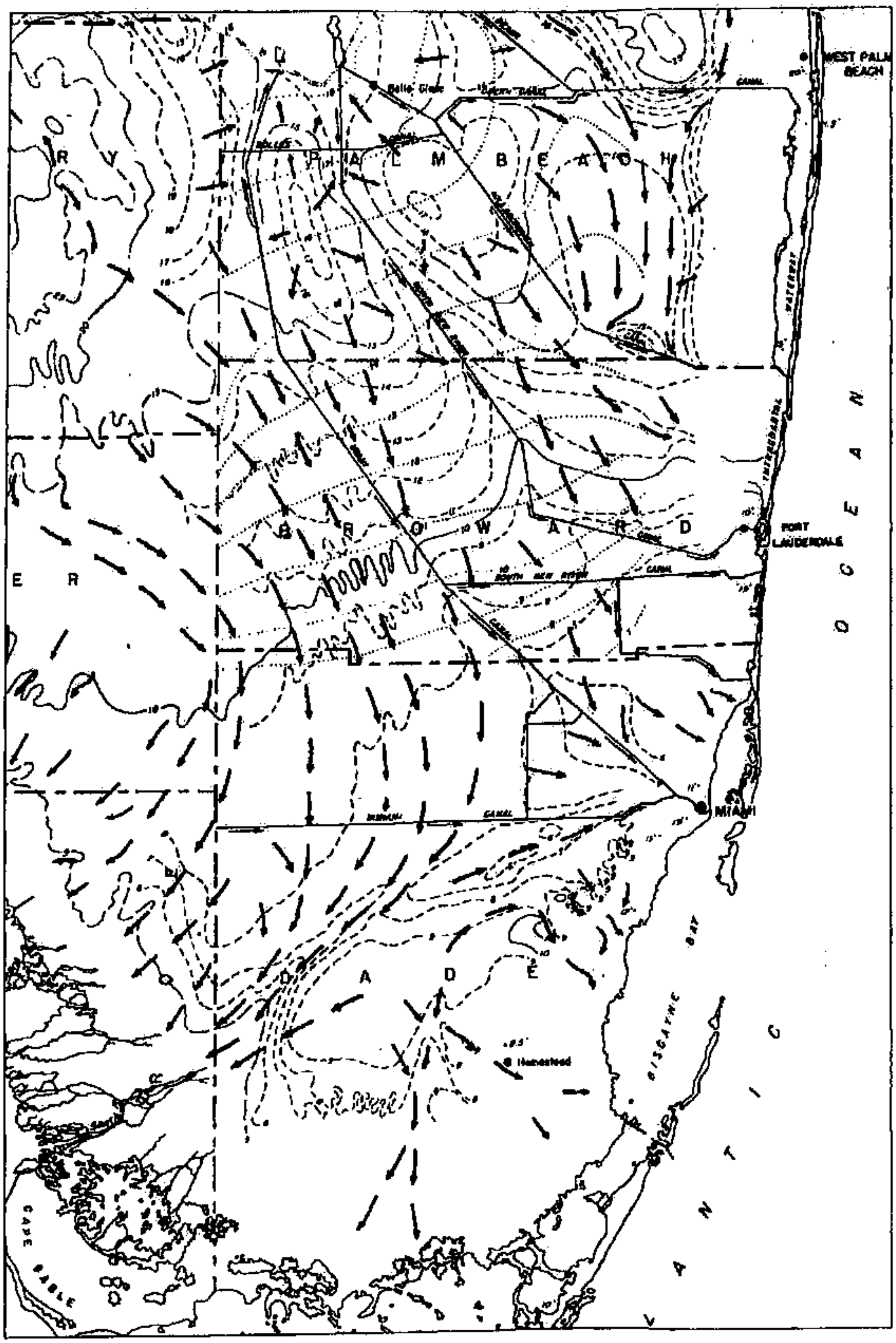
Operation of the Natural System. Historically a larger volume of water is believed to have flowed through the Everglades system. Accounts reviewed by Parker (1974) indicate that a large volume of water was stored in the Everglades

Figure 5. Extent of the Original Everglades, Including Adjacent Freshwater Marshes and Wet Prairies.



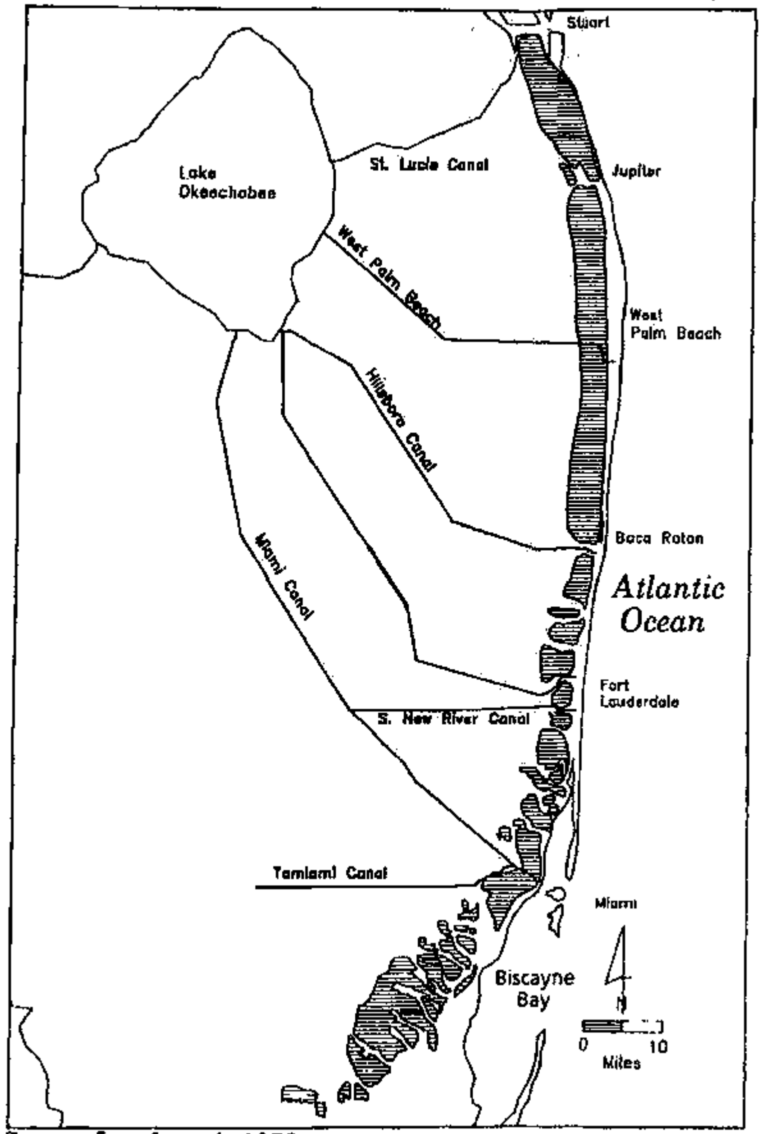
Source: Waller, 1982; Davis,1943b

Figure 6. Topographic and Drainage Map of South Florida (Davis, 1943a).



behind the coastal ridge (Harper, 1927). Water was transported to tidewater through a series of breaches in the coastal ridge (**Figure 7**), once a sufficient height was reached to pass this barrier, and as groundwater discharge to coastal lagoons (Harlem, 1979; Parker, 1974). During high water periods, water from the

Figure 7. Atlantic Coastal Ridge of Southeast Florida (shaded). Gaps indicate areas where water naturally discharged to tidewater during wet periods prior to construction of the canal system.



Source: Leach *et al.*, 1972

northeastern Everglades moved across the coastal ridge through the Loxahatchee River and and Hungryland Slough. Water flowed westward primarily through the Big Cypress Basin to the Ten Thousand Islands (Parker and Hoy, 1943; Davis, 1943b). Numerous natural flowways historically drained the Everglades along its eastern and southern borders. North of Broward County, there were few natural flowways through the coastal ridge to tidewater. The primary outlets along the southeast coast were the north New River, Little River, Miami River, and the transverse glades (Davis, 1943a; Parker *et al.*, 1955). At the extreme southern end, most of the flow was directed to the Gulf of Mexico and Florida Bay through Shark

River Slough and Taylor Slough (Davis, 1943a; Tabb *et al.*, 1962). In addition, due to direct connections through the coastal ridge, groundwater seeped through the porous limestone aquifer and emerged as freshwater springs in Biscayne Bay and the north Key Largo reef tract (Parker *et. al.*, 1955; Harlem, 1979). As late as the flood of 1947, water in the glades immediately west of Miami were reported to be 6 to 8 feet (1.8 to 2.4 m) deep over vast areas of the central portion of this region (Parker, 1974).

Various estimates have been made of the volume of flow within the Everglades system. An early estimate of 2,315,000 acre-feet (2.85×10^9 m^3)was provided by the Central and Southern Florida Flood Control District for a 4000 square mile (10,000 km^2) area bounded on the north by the southern rim of Lake Okeechobee, on the east by the Atlantic Ocean, on the south by Tamiami Trail, and on the west by the Everglades-Big Cypress drainage divide (CSFFCD, 1950; Wagner and Rosendahl, 1987). Parker *et al.* (1955) provided an estimate of 2,051,800 acre-feet (2.53×10^9 m^3) for a slightly smaller area without evaluation of percolation and surface runoff to the coast (Wagner and Rosendahl, 1987).

Alteration of Natural Drainage. Drainage of the Everglades region began in the early 1880s when Philadelphia industrialist, Hamilton Disston, under contract with the State of Florida (Trustees of the Internal Improvement Fund) and the Everglades Drainage District cut the first connection from Lake Okeechobee to the main body of the Caloosahatchee River. Prior to the channelization of the Caloosahatchee, a relict portion of the Fort Thompson Formation formed a natural dam, allowing water to flow through this area only after reaching a sufficient height (USCOE, 1892, 1895; Davis, 1943a). Drainage operations under the Disston contract ceased about 1889, after a substantial amount of canal construction had been completed, principally in the upper waters of the Kissimmee River. These works included the provision for the construction of the first canal connection between Lake Okeechobee and the upper end of the Caloosahatchee River. The Miami River was channelized beginning in 1903 and the falls were removed in 1908 (Harlem, 1979). The falls in the Miami River, as part of the Atlantic coastal ridge, acted in the same manner as the Fort Thompson Formation in the Caloosahatchee River. Several other canals were opened through the Atlantic coastal ridge to facilitate drainage of the Everglades. These canals included the Snapper Creek Canal, the Cutler Canal and the Coral Gables Waterway, which were finished between 1912 and 1913 (Harlem, 1979). Due to construction of these early canals, water levels in Lake Okeechobee dropped from 21.9 to 15 feet (6.7 to 4.6 m) above mean sea level between 1889 and 1927 (J. Meeder personal communication). The Corps of Engineers observed repeated overdrainage and navigation problems due to low water in the Caloosahatchee River beginning in 1926 (USCOE, 1927; 1928). Early uncontrolled drainage of South Florida lowered water tables 5 to 6 feet below 1900 levels, stressing natural wetland systems. Uncontrolled fires modified, damaged or eliminated much of the region's vegetation and soils (Alexander and Crook, 1974). By 1945, drainage of the northern Everglades caused noticeable amounts of peat loss (up to 6 feet in depth) as well as loss of water storage capacity (Davis, 1946; Jones, 1948). Parker *et al.* (1955) reported that the water table in Dade County had dropped 6 feet by 1955. Although droughts were common in the Everglades prior to drainage of the region, historical accounts indicate that pre-drainage conditions were much wetter than present day conditions.

Not until the mid-1950s did water control in the Everglades take precedence over uncontrolled drainage of the area. Development and implementation of a water management plan (the Central and Southern Florida Project for Flood Control and Other Purposes or C&SF Project) was adopted and largely constructed by 1962 to provide flood protection, water supply and environmental benefits to the region. Part of this massive water management plan involved use of the three water conservation areas (WCAs) for water storage and supply purposes.

6. Current Water Management and its Impacts on Hydrology.

Current Drainage Patterns. The current water management basins of southeastern Florida are remnants of the original Everglades. The WCAs are man-made basins created to preserve portions of the Everglades and to provide multiple uses, including water supply and storage for Palm Beach, Broward, and Dade counties. Over 100 years of drainage, flood control, and water management activity in south Florida have greatly altered the historic basin. Some 1,500 miles (2400 km) of canals and levees known collectively as the C&SF Project) have been constructed for flood control, water supply, and allied purposes.

The current hydrologic regime of today's Everglades varies both spatially and temporally from that of the natural system. The Everglades basin is filled during the summer by rainfall, and by surface and ground water connections throughout the system. Maximum water depths usually are reached in the late summer. Water levels decline slowly during the dry winter months. As water levels decline, the areal extent and depth of inundation also diminish. By spring, with increasing losses from evapotranspiration, water levels reach annual minima. Surface waters often disappear from the wetlands following extremely dry periods. In years with high rainfall and flow, inundation is year round (Parker, 1984).

The historic surface and ground water hydrology of southern Florida, including areas within what is now the ENP and the Big Cypress Preserve, have been altered by regional water management practices. The Everglades is now subdivided by hundreds of miles of canals and levees. Completion of a canal connecting Lake Okeechobee with the Caloosahatchee River in 1882 marked the beginning of significant alteration in the Everglades basin. **Table 5** shows the year of completion of some of the major levees, canals, pump stations, and control structures that have been constructed within the Everglades.

Leach *et al.* (1972) documented some of the effects that south Florida water management practices have had on Everglades hydrology. Surface waters may be retained by levees and released to downstream waters according to schedules that bear no resemblance to historical water delivery patterns. Ground water may be intercepted by canals and diverted to other basins or to the ocean. Watersheds in the eastern part of the ENP have been similarly affected by water management practices in areas that are external to the ENP borders (Rose *et al.*, 1981).

Beginning in the early 20th century, the timing and amount of surface water flow to Shark River Slough was increasingly influenced by man's activities. By 1945, uncontrolled drainage and land reclamation activities in South Florida had significantly lowered surface water and ground water levels in the lower east coast region compared to pre-development levels. Beginning in 1945, control structures were installed in the major canals discharging to the Atlantic Ocean to prevent overdrainage during the dry season and to reduce salt water intrusion into the Biscayne Aquifer. In 1953, a levee was completed along the eastern side of the Everglades. Consequently, flow to the Atlantic Ocean through the Hillsboro, North New River, and West Palm Beach Canals was reduced by 25 percent (Leach *et al.*, 1972). Flow was diverted south, with most of the increase in flow occurring along the eastern Everglades.

Table 5. Completion Dates of Major South Florida Water Management Facilities.

Levee/Canal	Year of Completion
1. Miami Canal	1912
2. North New River Canal	1912
3. Hillsboro Canal	1915
4. West Palm Beach Canal	1915
5. St. Lucie Canal	1924
6. Caloosahatchee Canal	1884, 1918
7. Lake Okeechobee Dike:	
Low Muck Levee	1926
Hoover Dike	1938
8. Tamiami Canal	1928
9. Levee 30 and Borrow Canal	1952
10. Everglades Agricultural Area Levees completed	1959
11. Lake Okeechobee Pump Stations:	
S-2	1957
S-3	1958
S-4	1975
12. EAA Pump Stations:	
S-5A	1955
S-6	1961
S-7	1962
S-8	1975
13. Conservation Area No. 1	1961 *
14. Conservation Area No. 2	1961 *
15. Conservation Area No. 3	1962 *
16. Levee 67A, L-67C, and Borrow Canals	1967
17. Levee 28 and Borrow Canal	1963
18. L-28 Interceptor and Feeder Canals	1967
19. C-38 Canal	1970
20. C-111 Canal, L31N	1967
21. Structure 197	1967
22. Levee 67 Extension and Borrow Canal	1968
23. Levee 31W and Borrow Canal	1971
24. Structures S-333 and S-334	1978
25. Pump Station S-332	1980
26. Pump Station S-331	1983

* = Surrounding levees largely completed and spillways functional.
Note: In some cases, substantial changes occurred after the indicated completion date.

The C&SF Project. The structural tools necessary for achieving the objectives of water management in the District are provided by the Central and Southern Florida Project for Flood Control and other Purposes (C&SF Project). Operation of the C&SF Project is governed by water management plans developed through cooperation of the U.S. Army Corps of Engineers (USCOE), the District, ENP, and a multitude of local interests. This section presents a broad overview of the CSFFC Project and describes the general operation of the system.

The C&SF Project, approved by Congress in 1948, was largely designed and built by the USCOE. The Project covers an area of more than 16,000 square miles (41, 000 km^2), extending from the Kissimmee River Basin, just south of Orlando, to the southern tip of Florida within ENP. Today the C&SF Project consists of 1,500 miles (2,400 km) of canals and levees, 125 major water control structures, 18 major pumping stations, 13 boat locks, and several hundred minor structures.

Figure 8 shows the major components of the C&SF Project while **Figure 9** shows a schematic diagram of the system. Note that there are six major reservoirs: Lake Okeechobee WCA-1, WCA-2A, WCA-2B, WCA-3A, and WCA-3B. The system is generally operated to provide flood protection during the wet season by placing water into storage and discharging excess water to the ocean (**Figure 10**) and to supply water from storage in the dry season for irrigation and municipal water

Figure 8. Major Features of the Central and Southern Florida Project for Flood Control and other Purposes.

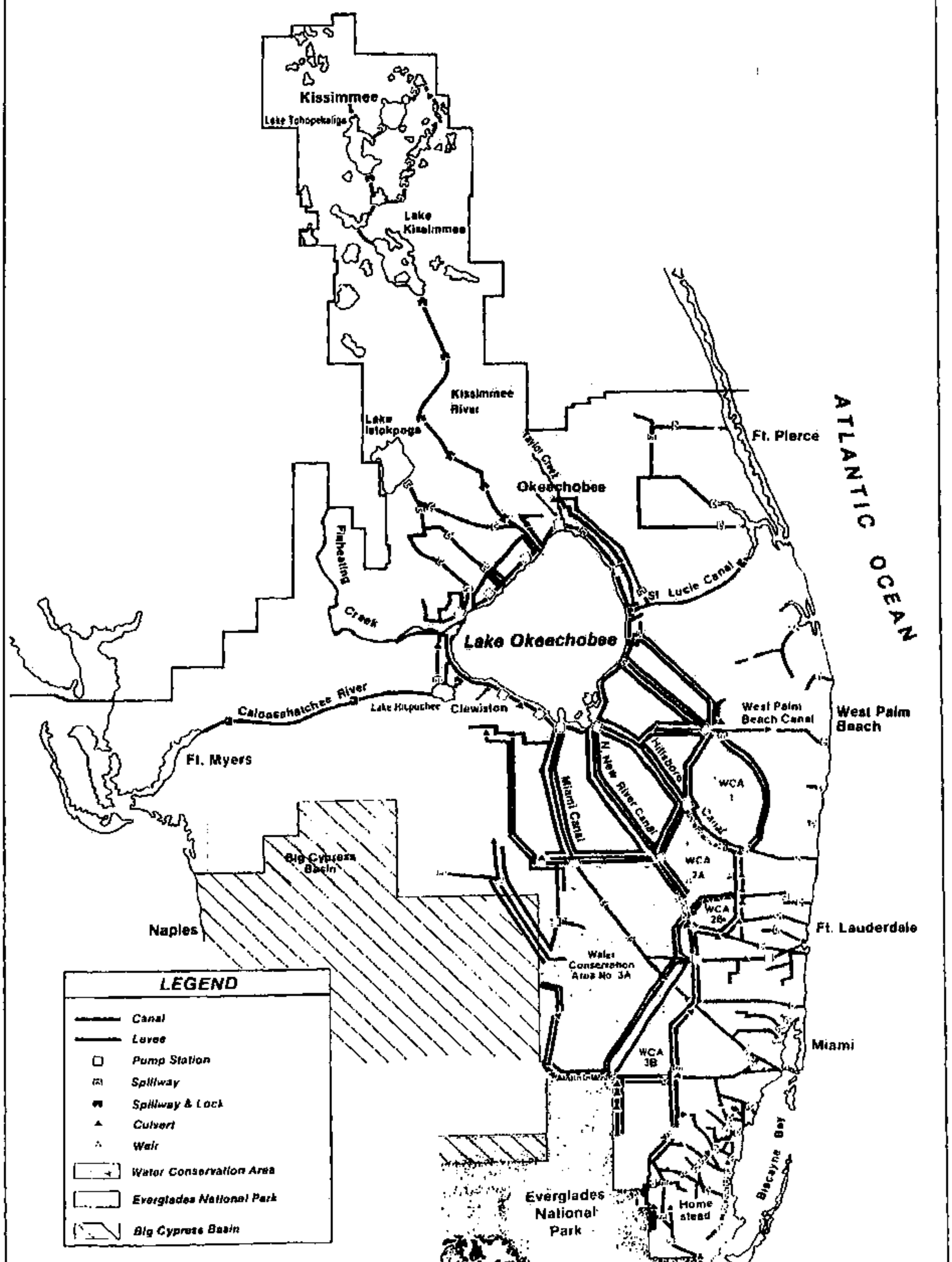
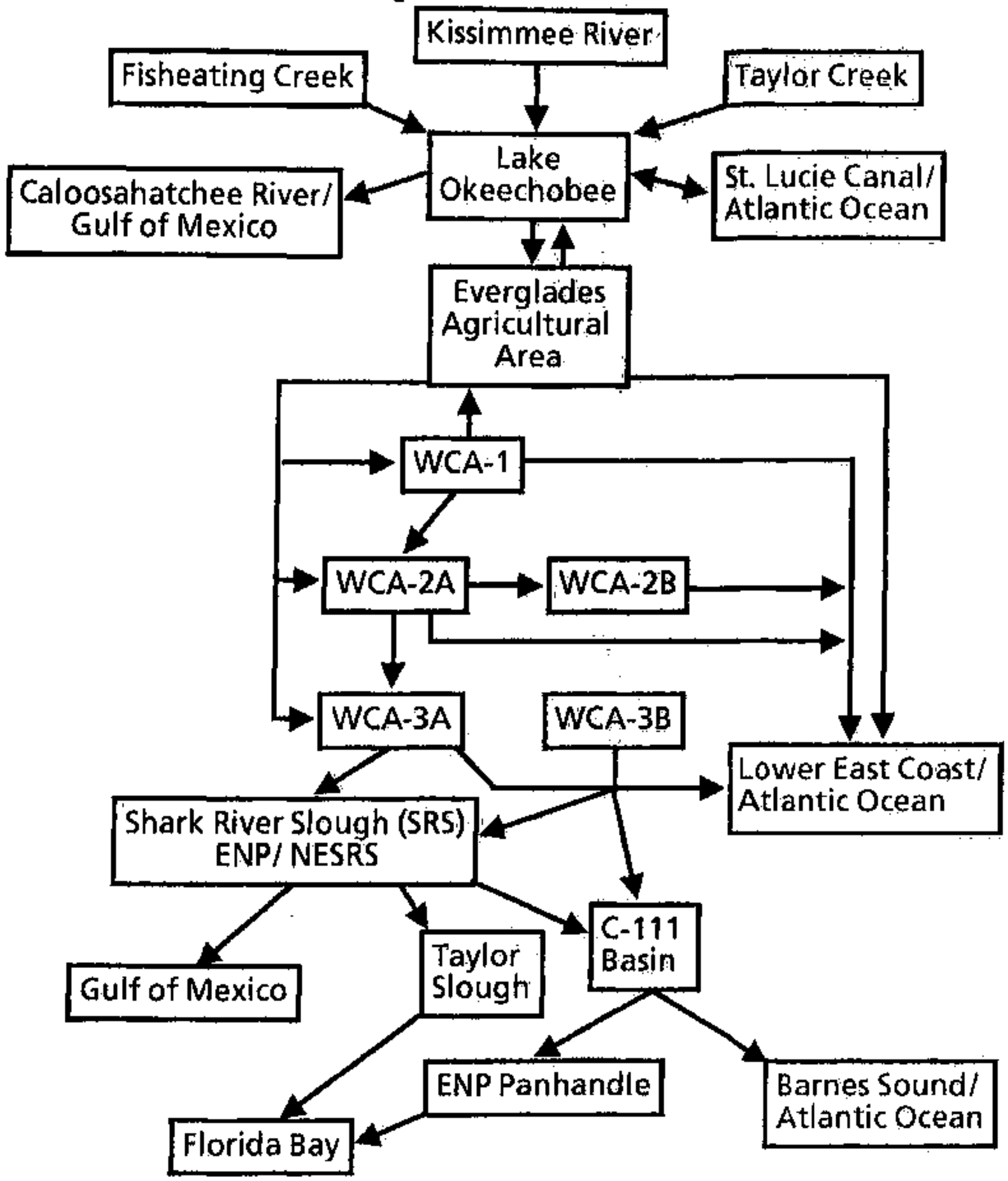


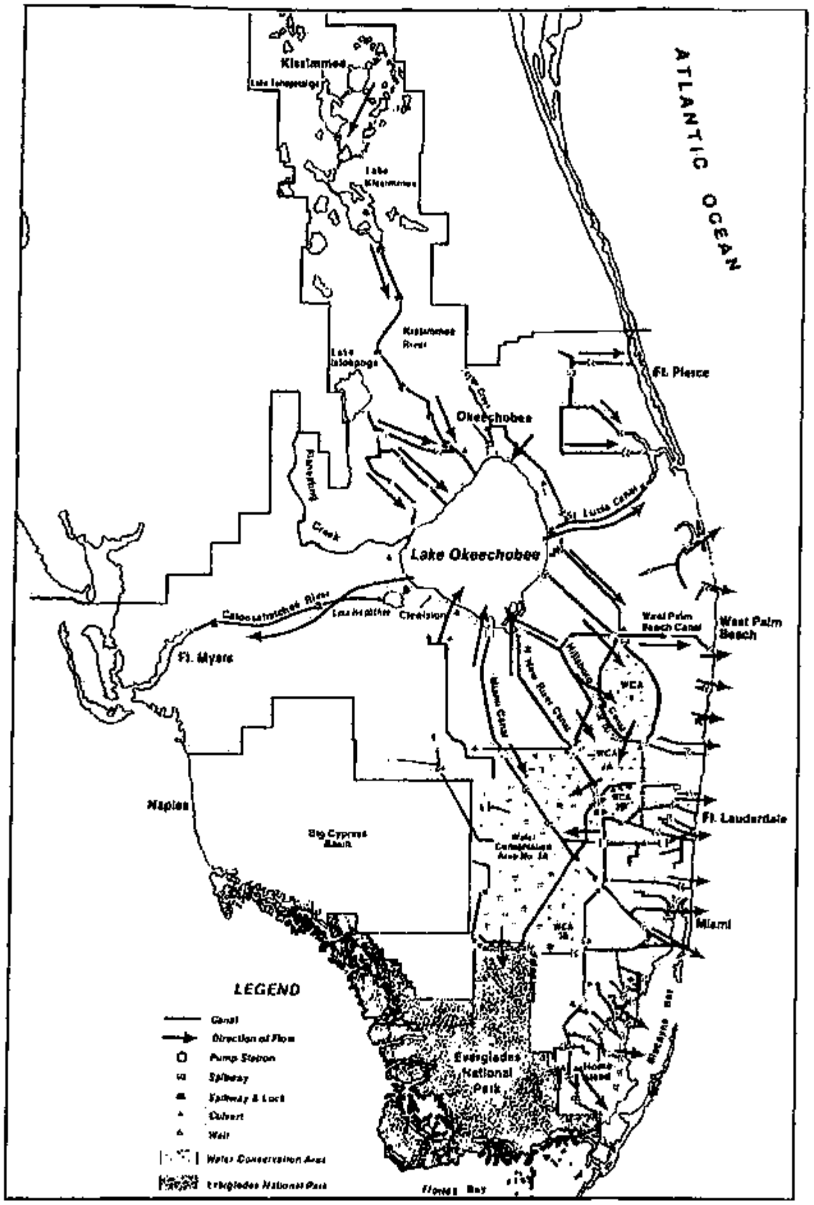
Figure 9. Schematic Diagram of Water Movement in the SFWMD.



supply (**Figure 11**). Regulation schedules for the WCAs and for Lake Okeechobee allow for the highest water levels at the beginning of the dry season to provide maximum water supply. By June 1, the beginning of the wet season, water levels are at their lowest levels to make storage available for wet season rainfall. Every effort is made to insure that these operational strategies protect the environmental and water quality of the lakes, wetlands, and estuaries of south Florida.

Development. The hydrology of the District is impacted by development in primarily two ways: (1) by increasing the amount of surface runoff relative to the amount that occurred prior to development and (2) by reducing the amount of surface storage available. The first case may result from any kind of development. The second case occurs where wetlands are drained and filled or diked, or where flood protection is provided.

Figure 10. Operation of SFWMD Facilities for Flood Control.

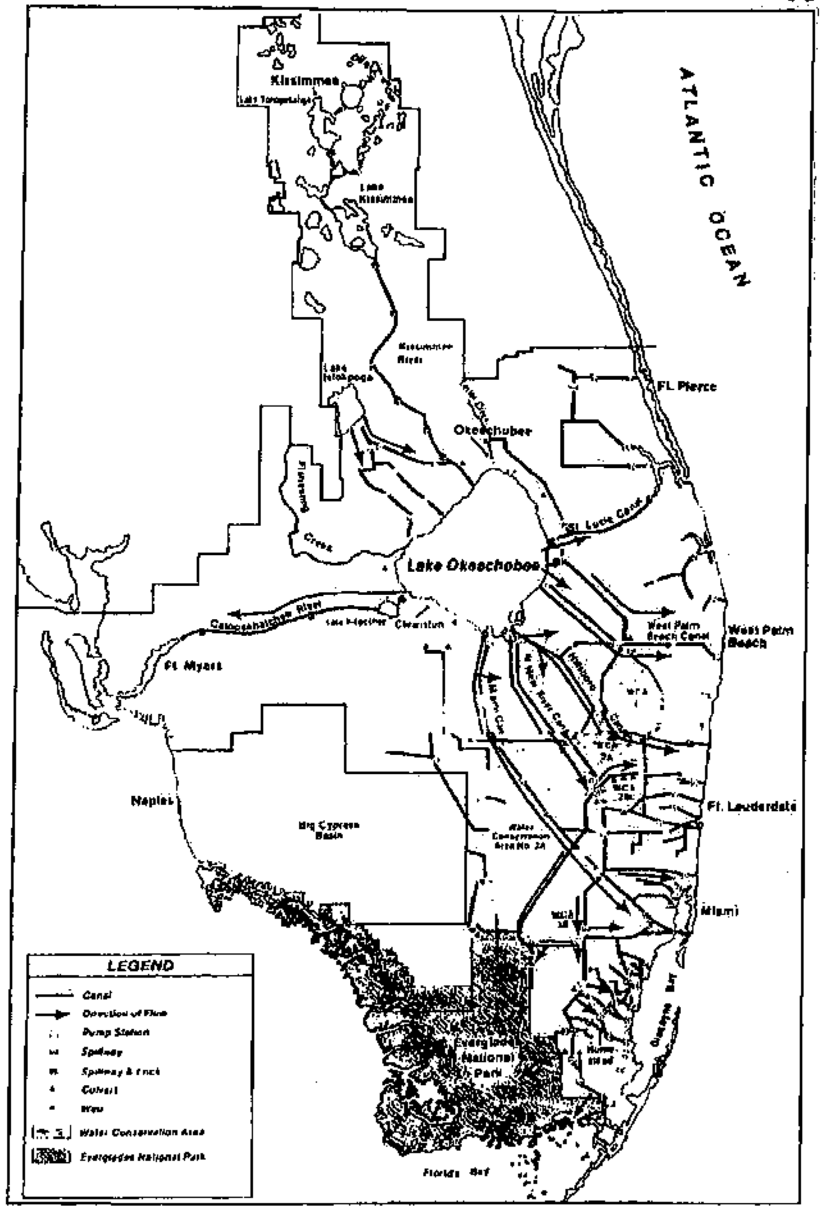


Source: SFWMD

Land use has a significant impact on the amount of surface runoff entering local streams or canals. Much of the surface area of an urban area (e.g., roofs, roads, and parking lots) is impervious to water. Consequently, much of the rain falling on these areas cannot seep into the ground, and it becomes surface runoff. Some water may be detained and will evaporate, but a high percentage of rainfall may enter local canals or streams by surface flow in an urban area, resulting in high stream flows during rain events.

Vegetated areas intercept and retain a large part of the rainfall and subsequent surface runoff from a rain event. This intercepted water has additional opportunity to evaporate or seep into the ground. In general, a smaller percentage of the rain falling on a vegetated area will enter local streams and canals as surface

Figure 11. Operation of SFWMD Facilities for Water Supply.



Source: SFWMD

water runoff than for a comparable urban area. As a result, stream flows are moderated compared to urban areas (**Figure 12**).

Wetlands and poorly drained uplands subject to flooding typically store water from rain storms and then slowly release it. This has the effect of reducing the amount of the flood peak and of extending the recession of the hydrograph. Superposition of the water management network on the natural Everglades hydrologic system has decreased the hydrologic head, altered the way water flows through the system and subsequently lowered the water table (**Figure 13**). Wetlands and other flood-prone lands provide natural flood protection to downstream areas. When wetlands are drained and filled or diked, that storage is removed from the hydrologic system. Flood peaks are increased and stream flows during dry periods are reduced. The District's current regulatory policy restricts the amount of

Figure 12. Stream Flows from Various Land Uses.

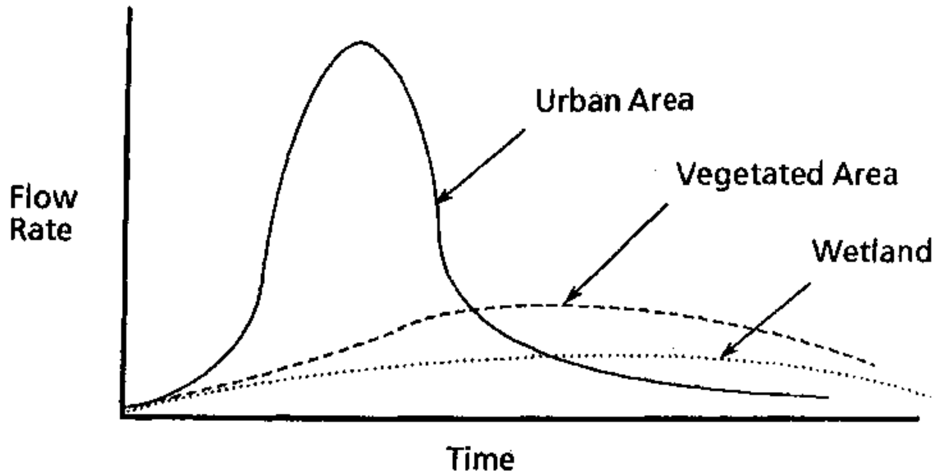
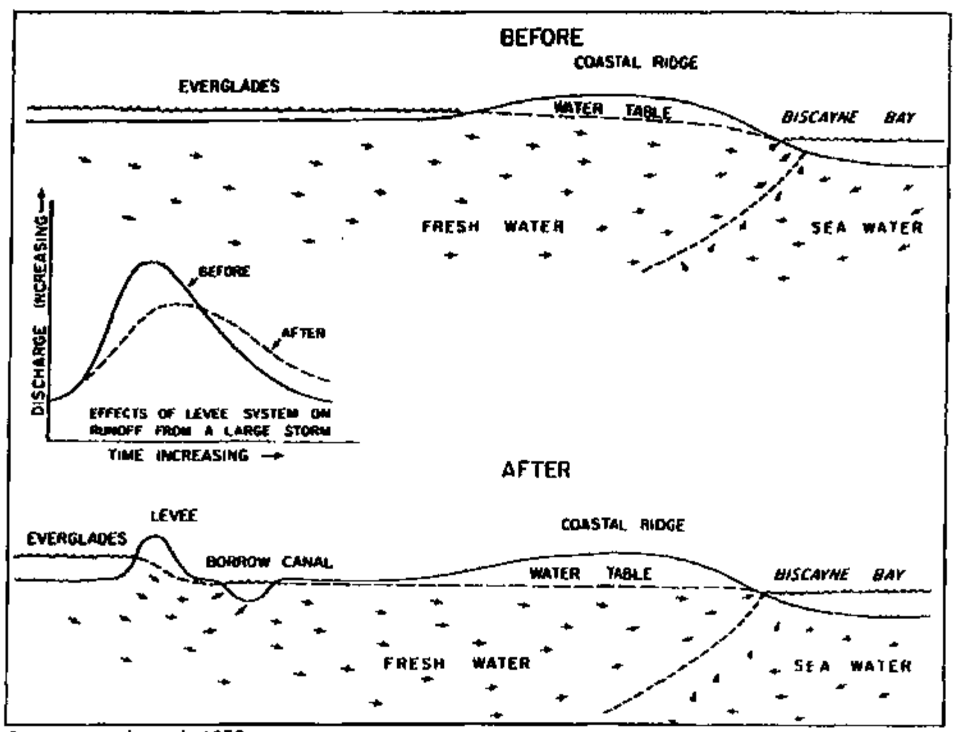


Figure 13. Direction of flow and water levels in a typical east-west section from the Everglades through the coastal ridge to Biscayne Bay. Conditions are shown during a wet period, before and after water management systems were operational.



Source: Leach *et al.*, 1972

post-development discharge, prohibits draining of wetlands, and requires that compensating storage be provided if any area ordinarily providing surface storage is filled or diked (see Chapter 40E-4140 Fla. Admin. Code).

Impacts Due to Changes in Hydroperiod. The Everglades system has evolved as a result of many years of climatic fluctuations, including extreme events such as hurricanes, floods, and droughts. Natural stochastic variations within this system are necessary for its continued health and survival, but are difficult to mimic within the limits of the man-made C&SF project. Implementation of the rainfall delivery schedule for ENP has been a successful attempt to refine the operational strategies of artificial control structures to simulate a more natural response to randomly changing conditions within the Everglades Additional physical modifications to improve water deliveries to ENP are being developed by the USCOE.

Construction of the three WCAs, with attendant internal canal systems, has had two pronounced impacts on hydroperiods. All three WCAs share these common problems:

(1) Water tends to pond in the southern portions of each WCA, sometimes at depths that have adverse effects on some Everglades plant communities such as wet prairies and tree islands (Dineen 1972; 1974).

(2) The northern portion of each WCA dry too quickly, too often causing loss of wading bird habitat, increasing the frequency of fires which cause subsidence of peat soils and damage to tree islands and wet prairie communities.

Some attempts to correct hydroperiod impacts in the past include the construction of S-339 and S-340 in WCA-3A to disperse canal flow from the Miami Canal (C-123) into the northern marsh in wet periods (during pumping at S-8), and to stop overdrainage of these northern marshes in dry seasons by preventing the Miami Canal from continually moving water southward (Zaffke, 1983). These alterations tend to slightly reduce the depth of water in the southern, ponded area. Another structure, S-10E, was constructed in Levee 39 in the northern apex of WCA-2A. This vast marsh area received water only from direct rainfall after completion of WCA-2. S-10E provides a method to convey water from WCA-1 to the northern portion of WCA-2A for a better distribution and extension of the hydroperiod. The S-333 water control structure has been used to deliver water to Northeast Shark River Slough (NESRS), reflooding the head waters and attempting to reconnect the historic slough. These water dispersal mechanisms have been beneficial, but are not the ultimate solutions to existing problems.

Water Regulation Schedules. Regulation schedules for the WCAs were designed on the basis of several important considerations. The schedules generally allow water levels to increase during the rainy season to reach maximum levels at the end of the wet season. The levels are then permitted to drop so that the lowest point occurs at the end of the dry season. The WCAs can thus be used for flood water storage and retention during the wet season, and will be as full as possible to provide water supply during the oncoming dry season (Neidrauer and Cooper, 1989). This water is used to supply east coast wellfields and maintain a freshwater head at coastal structures to prevent saltwater intrusion.

A constraint that was incorporated into the original schedule, was to provide protection for marsh vegetation. The design of the WCAs was based on the ability of marsh (sawgrass) vegetation to prevent hurricane-induced waves, generated within the WCAs, from breaching the levees (Cooper, 1990, in press). The vegetation prevents mass movement of water. Loss of emergent vegetation in the WCAs would require costly levee redesign and reconstruction. Regulation schedules for all three areas have been modified over the years in an effort to balance water supply and flood control needs with environmental considerations.

Hydraulic Connections. An important factor in flood control and water management in southeast Florida is the hydraulic connection between the Biscayne Aquifer and tidewater and between the Biscayne Aquifer and the canals that intrude into the aquifer. These hydraulic interconnections have many effects (Klein and Hull, 1978) including the movement of ground water from the interior to coastal areas where it can maintain adequate levels to retard saltwater intrusion. Historically, groundwater also provided freshwater discharge to estuaries.

The effectiveness of hydraulic connections between the aquifer and the canal system is indicated by the rate at which canal water can infiltrate downward and laterally into the aquifer during dry periods, if water levels in the canals are higher than adjacent groundwater levels. Water quality impacts on the aquifer from poor quality canal water are most likely to occur in canal reaches that are located near wellfields. Large groundwater withdrawals can lower the local groundwater stages in the vicinity of the wellfields, resulting in the transfer of water from the canals to adjacent underground storage. Other water quality impacts from hydrologic interconnections may occur where contaminated groundwater upwells in an estuary. This type of contamination may be occurring near the South Dade Landfill where subsurface contamination is suspected of moving laterally through groundwater into Biscayne Bay (Shinn and Corcoran, 1988).

Flood Protection. One of the primary objectives of the C&SF Project was to provide flood protection for South Florida. The water management system consists of multiple pump stations, control structures and canals in the Everglades planning area. The three WCAs provide temporary storage of flood waters in the interior of the southern peninsula. Stormwater generally enters these areas via pumping facilities which were specifically designed to meet the flood control requirements of their respective watersheds. The pump stations are operated based on a combination of stage and precipitation factors which indicate the potential for flooding conditions. Operation of the pump stations serving the EAA has been altered over the past decade to increase the utilization of the WCAs for flood water storage. The Interim Action Plan (1979) and subsequent modifications were designed to reduce the volume of nutrients entering Lake Okeechobee, and diverted stormwater formerly pumped into the lake to the WCAs.

Releases from the WCAs take into consideration both critical flood levels and downstream impacts of excessive and untimely discharges. Recent operational modifications such as the Rainfall Driven Model (MacVicar, 1985) for releases to ENP consider both the seasonal needs of the receiving body as well as the flood control limitations of the C&SF Project.

Flood protection for a basin within the District is usually described in terms of the most severe storm that can occur over the basin without causing flooding. A severe storm is described by the frequency with which it may occur. On a long term average, a storm of a given intensity may occur, for example, once in every ten years (i.e., the storm has a ten percent chance of occurring in any given year). It must be emphasized, however, that a storm of given intensity may occur at any time regardless of the frequency assigned to it. For example, two storms of an intensity expected to occur once in every one-hundred years (1-in-100 year storm) occurred in northern Palm Beach County within three months in the early 1980s (Lin, 1982; Lin and Lane, 1982; SFWMD, 1982).

The USCOE specifies a Standard Project Storm (SPS) for South Florida. The amount of runoff generated from a SPS is termed a Standard Project Flood or SPF. The rainfall generated by a SPS are 25 percent greater than the amounts that would occur during a 1-in-100 year storm. The SPS storm is assumed to occur during the wet season when water tables are high and soils are wet. These conditions will maximize the amount of runoff. The flood protection for a basin may be given as the return interval of the most severe storm that can occur without flooding the basin (e.g., 1-in-10 year) or by the percent of the SPF that can be passed from the basin without flooding (e.g., 30 percent of the SPF).

Saltwater Intrusion. In coastal areas of South Florida, fresh and salt groundwaters meet. The fresh groundwater is less dense than the salt groundwater so that the fresh water floats on, but does not mix with, the saltwater. The Geiben-Herzberg Principle (Fernald and Patton, 1984) is a general rule which states that the boundary between fresh and saltwater occurs about 40 feet (12 m) below sea level for each foot (0.3 m) that the fresh groundwater table extends above sea level. For this reason, the water table in coastal areas should be maintained high enough to prevent salt water from entering the local surficial aquifer and contaminating nearby well fields. This is accomplished by maintaining canal levels high enough so that the hydraulic interconnection of the canals and the aquifer maintains a freshwater gradient that is adequate to prevent intrusion of saltwater into the fresh surficial aquifer.

7. Future Hydrologic Threats to the Everglades System.

Continued Encroachment of Land Development, Loss of Seasonal and Short Hydroperiod Wetlands, and Overdrainage. Continued expansion of urban and agricultural development in and adjacent to the planning area is a major continuing threat to Everglades aquatic resources. Measures need to be taken by Federal and state agencies and local entities to recognize the importance of remaining seasonal wetlands, and protect these critical resources from urban and agricultural development.

Direct loss of Everglades wetlands and important peripheral wetlands began at the turn of the century and continues to the present day. Historical accounts suggest that the Everglades may have only dried out during the most severe droughts. Depressional features such as sloughs, ponds, or alligator holes retained water until the next rainy season. In this natural system, the sequence of events left the southern portions of the system (Shark Slough and ENP) wet, except during a drought (Parker, 1974). The existence of this diversity of wetlands (long hydroperiod wetlands in conjunction with short hydroperiod wetlands) provided an 'edge effect.' Vast expanses of deeper water habitat were available for aquatic life during high water conditions. Organisms from these large areas then became concentrated in smaller pools as the area dried. The seasonal drying and concentration of the food supply was widely exploited by wading birds and other predators. The wetland systems that provided this function, especially in the area known as the the transverse glades, are now mostly lost to the Everglades because of development. The loss of this habitat is thought to have had a severe impact on the breeding success of wading birds throughout the Everglades system. Many of those short- hydroperiod wetlands, which served as early dry-season feeding habitats for wading birds, are now lost because of wetland conversion for development. Loss of wetlands and associated aquatic habitats is a continuing threat to these natural systems.

The relationships among natural (seasonally fluctuating) hydroperiod conditions, wetland diversity and productivity and bird populations have been well documented in South Florida. Since drainage and development have altered most of South Florida's natural systems, the best and most extensive areas of natural wetlands are found within Everglades National Park and the Water Conservation Areas. Davis et al., (1987) in their studies of wading bird communities within Everglades National Park and concluded that "restoration of natural water distribution . . . into the southern Everglades would create the conditions necessary for optimum primary production." The keys to protection of the remaining viable wetlands outside of the ENP and WCAs include maintenance of natural hydroperiods, natural water distribution patterns and appropriate water depths. These conditions are largely incompatible with drainage urban or agricultuaral land development.

Climatic Changes. Three possible climatic changes appear as most likely to impact the Everglades as follows: (1) a decrease in rainfall and a change in its distribution; (2) global warming; and (3) a rise in sea level.

Gannon (1978) has suggested that extensive urbanization and wetlands drainage in South Florida has decreased wet season rainfall. Shih (1983) demonstrated that averaged over all of south Florida mean annual rainfall has decreased and the seasonal distribution rainfall has changed in recent years. In his analysis the most significant breakpoint was shown to be 1970. Shih concluded that the reduction in rainfall was due to shorter and drier wet seasons and to fewer tropical cyclones passing over South Florida. Shih also showed dry season rainfall after 1970 to be greater than prior to 1970. The differences between wet and dry season rainfall has decreased, as has the overall variation in rainfall. Not all changes identified by Shih were statistically significant (at the 90 percent confidence level). Most significantly affected were the Kissimmee River Valley and southwest coastal areas. In the Everglades planning area, there was not a significant decrease in mean annual rainfall, but wet season rainfall was significantly decreased in parts of the EAA and WCA-1 and WCA-2. Most of the Everglades south of WCA-3 showed a significant decrease in high intensity rainfall events (greater than three inches per day).

E. MAJOR EVERGLADES PLANT COMMUNITIES.

1. Introduction.

Descriptions of historical Everglades vegetation communities *circa* 1934 are provided by Davis (1943a). The historic Everglades was comprised of roughly 2.5 million acres (1 million ha) of freshwater marsh. As a result of drainage of these wetlands for agricultural and urban development, only 50 percent of the original ecosystem remains today (Schortemeyer, 1980). This drainage and urban development has impacted many areas of the remaining marsh and caused changes in species composition, spatial distribution and ecosystem processes due to altered hydrological regimes and degraded water quality (Alexander and Crook, 1984).

The Everglades are made up of a series of habitats formed around various physical features, dominated by a few select species of plants, or composed primarily of one species. The primary components of this system are the periphyton (algae) community, the sawgrass community, the wet prairie, aquatic sloughs, bayheads or tree islands, willow heads, tropical hardwood hammocks, cypress forest, and coastal mangrove forest communities (Davis, 1940; Davis, 1943a,b; Loveless, 1959; VanMeter, 1965; Gleason, 1974; Tabb *et al.*, 1967; Steward, 1974; Goodrick, 1984; Craighead, 1971). These native plant communities are interspersed throughout the Everglades system, effectively creating a mosaic of distinct and valuable habitat types. The historic border of this system was composed of seasonal or short hydroperiod wetlands and upland pine habitat (Davis, 1943a). These are the communities that have fallen under the heaviest pressure for urban and agricultural development. In the southern part of the system, freshwater wetland communities give way to muhly grass (***Muhlenbergia filipes***) prairies, upland pine and tropical hardwood forests, as well as tidally influenced mangrove forests more characteristic of the southern reaches of ENP and Florida Bay. Important vegetation communities, which lie outside the current Everglades marsh but are considered tributary inflows to the system, include; cypress forests (located east of WCA-1, and west of the WCA-3 in the Big Cypress National Preserve) and the pine flatwoods (found in eastern Hendry, and in western Palm Beach, Broward, and Dade counties).

The relationship between plant communities and hydrologic regimes has been investigated by numerous scientists for more than four decades (Davis, 1943a,b; Egler, 1952; Craighead, 1971; McPherson, 1973; Pesnell and Brown, 1973; Olmstead *et al.*, 1980; Zaffke, 1983; and Gunderson, 1987). A gradient of water depths and associated hydroperiods (length of inundation) exists between each of the above described wetland communities. Upland hammocks and pinelands are the driest communities, followed in order by tree islands, sawgrass stands and wet prairies. Aquatic sloughs are the wettest with almost continuous inundation.

2. Periphyton.

Attached algae, or periphyton, are a conspicuous and ecologically important element of the Everglades ecosystem. Everglades periphyton are represented primarily by calcareous blue-green algae, hard water diatoms, desmids and a few species of filamentous green algae. These algal communities probably represent a major component of the detrital-based Everglades food web providing organic food matter and habitat for a wide variety of grazing invertebrates and forage fish which are in turn consumed by wading birds, reptiles and sport fish (Tabb *et al.*, 1967;

Craighead, 1971; Carter *et al.*, 1973, Wood and Maynard, 1974; Browder *et al.*, 1982). Wood and Maynard (1974) indicate that a large portion of the southern Everglades primary production appears to be derived from periphyton algal mats. Laboratory studies suggest that periphyton may be an important food source for Everglades crayfish (Pope *et al.*, 1981),and forage fish (Hunt, 1953, Kolpinsky and Higer, 1969), both important components of the Everglades food web. Periphyton photosynthesis and respiration play an important role in controlling diurnal dissolved oxygen, carbon dioxide and calcium concentrations within marsh surface waters (Hunt, 1961; Gleason, 1972; Gleason and Spackman, 1974; Wilson, 1974; Belanger and Platko, 1986). Algal photosynthesis accounts for a large portion of calcium precipitation within the marsh and is responsible for the formation of marl soils within the southern Everglades (Gleason, 1972; Gleason and Spackman, 1974). Periphyton provide feeding habitat and cover for Everglades invertebrates and fish and provide an important microhabitat for the survival of the eggs and larvae of insects and fish during dry periods (Harrington, 1959).

Water quality (phosphorus, major ion concentrations and pH) and hydroperiod are the major factors which appear to influence the species composition and growth rates of Everglades periphyton communities (Swift, 1981, 1984; Swift and Nicholas, 1987; Browder, *et al.*, 1981; Flora *et al.*, 1987). Calcareous (calcium carbonate precipitating), filamentous blue-green algae (*Scytonema hoffmani* and *Schizothrix calcicola*) and a group of hard water diatoms (e.g. *Mastogloia smithii* v. *lacustris*) are the dominant algal species present, both in species numbers and areal extent, throughout the freshwater marshes of the WCAs and ENP (VanMeter, 1965; Gleason, 1972, 1974b; Gleason and Spackman, 1974; Browder *et al.*, 1981; Swift, 1981, 1984; Swift and Nicholas, 1987) and are representative of calcium rich, low nutrient, alkaline, hard water conditions. In contrast, filamentous green algae (*Mougeotia* sp and *Spirogyra* sp.) accompanied by a rich desmid (green algae) flora are reliable indicators of acid, soft water conditions characteristic of the interior of WCA-1 (Swift, 1981; Swift, 1984; Swift and Nicholas, 1987).

Periphyton communities of both the WCAs and ENP probably evolved within a nutrient-limited ecosystem. The presence of low growth rates, low internal concentrations of elemental phosphorus within periphyton cell tissue, marsh surface waters and Everglades soils, all indicate that phosphorus is the growth limiting nutrient for interior marsh periphyton and that rainfall is probably the primary nutrient source for these algae. Due to its low availability, inorganic nitrogen ($NO_3+NO_2+NH_4$) may also seasonally function as a co-limiting nutrient (Davis *et al.*, 1987; Swift and Nicholas, 1987).

In WCA-2A and WCA-3A research studies have shown that elevated phosphorus levels have been shown to significantly impact the species composition and community structure of Everglades periphyton communities (Swift, 1981, 1984; Swift and Nicholas, 1987). In WCA-2A , high phosphorus and nitrogen levels were shown to promote major changes in algal species composition, reduce algal species diversity and stimulate the growth of pollution-tolerant species (Swift, 1981; Swift and Nicholas, 1987). Nutrient-enriched areas of the marsh exposed to high concentrations of phosphorus result in a reduction in the numbers of species present and and a dramatic increase in the population density (biomass) of pollution-tolerant species such as *Microcoleus* sp. (Swift and Nicholas, 1987). Water quality impacts on the WCA periphyton community are discussed in more detail in Part IV, section B.6 of this report.

3. Aquatic Macrophytes.

Sawgrass Communities. Sawgrass *(Cladium jamaicense)* is one of several dominant vegetation community types found throughout the freshwater Everglades marsh. Estimates of the extent of sawgrass range from 65 to 70 percent of the remaining Everglades marsh (Dineen, 1972; Kushlan, 1987; Loveless, 1959; Schomer and Drew, 1982; Steward and Ornes, 1975a). Sawgrass is a perennial sedge and not actually a grass as the common name implies. Sawgrass typically occurs on land elevations slightly higher than aquatic sloughs but lower than bayhead tree islands. In the northern Everglades, sawgrass that grows in deep peat soils tends to be tall and dense, reaching heights up to 10 feet (3 m), whereas sawgrass which develops over marl soils is typically shorter, averaging 2.5 to 5.0 feet (0.8 to 1.5 m). Southern sawgrass communities also tend to be less dense, possibly as a response to the low nutrient content of marl soils. Sawgrass communities range from almost pure stands to mixed vegetation including maidencane *(Panicum hemitomon)*, arrowhead *(Sagittaria lancifolia)*, water hyssop *(Bacopa caroliniana)*, and spikerush *(Eleocharis cellulosa)*. Areas which experience shorter hydroperiods allow for invasion by small trees and brush such as willow *(Salix spp.)*, wax myrtle *(Myrica cerifera)*, dahoon holly *(Ilex cassine)* and salt bush *(Baccharis halmifolia)*.

Sawgrass is well adapted to survive stress from either flooding or burning, which accounts for the success of this species' survival under flood and drought conditions characteristic of the Everglades. Although capable of surviving variable water depths from dry soil to flooding, sawgrass loses its viability when exposed to prolonged high water conditions (Hofstetter and Parsons, 1979; Davis, 1989). Sawgrass has a very low requirement for phosphorus and other minerals (Steward, 1974; Steward and Ornes, 1975a, 1975b; Volk *et al.*, 1975), a trait which allows survival in the oligotrophic waters of the interior Everglades marsh.

Sawgrass adaptations to fire have been well studied (Davis, 1943b; Loveless, 1959; Craighead, 1971; Forthman, 1973; Yates, 1974; Hofstetter and Parsons, 1979; and Wade *et al.*, 1980). Sawgrass leaves are highly flammable, but the plant's meristem is protected by spongy soft tissue which is not flammable except under severe drought conditions. Regrowth after fire is rapid (Forthman, 1973; Tilmant, 1975). However, sawgrass is especially sensitive to high water conditions after a burn when it can be killed by extended submergence. Fire is the dominant factor in maintaining sawgrass as a sub-climax community within the Everglades ecosystem (Wade *et al.*, 1980).

Hydroperiod and water depth are important factors in both the growth and reproduction of sawgrass. Toth (1987) demonstrated that sawgrass exposed to deep and widely fluctuating water levels exhibit tussock (cylindrical mounds of undecayed leaf bases) formation, slower growth rates, heavy early mortality, and high rates of new shoot production. Conversely, shallow, stable, water levels result in rapid growth rates, extended survival of sawgrass culms (leaves) and limited new shoot production.

Wet Prairies. Wet prairies are seasonally inundated wetland communities with intermediate hydroperiod and depth requirements. Requirements for wet prairies hydroperiod lengths and water depth falls between that for sawgrass marshes and aquatic sloughs (McPherson *et al.*, 1976). Common emergent aquatic plants in wet prairies include: spikerush *(Eleocharis cellulosa)*, beak rush *(Rhynchospora tracyi)*, maidencane *(Panicum hemitomon)*, arrowhead *(Sagittaria latifolia)* and pickerel weed *(Pontederia lanceolata)*. The wet prairie community is found over both peat and marl soils, with each soil type supporting distinct plant associations. Loveless (1959) described the characteristic wet prairie communities which develop over peat as *Eleocharis, Rhynchospora*, and *Panicum* flats although at least 25 different species typically occur in these associations. Important submerged aquatics include bladderwort *(Utricularia* spp.) and *Ludwigia* spp. as well as the periphyton association. Wet prairies require seasonal inundation with standing water present for six to ten months of the year (Schomer and Drew, 1982). Seasonal drying of these marshes with moist soil conditions are required for seed germination and establishment of new seedlings (Dineen, 1972).

During the rainy season, wet prairies and aquatic slough communities provide habitat for the development of a wide variety of aquatic invertebrates (freshwater shrimp, amphipods, snails, crayfish and insect larvae), and numerous forage fish species. As water levels recede in the fall and winter months, organisms from the wet prairies migrate to the remaining ponds and sloughs. As a result, wet prairie and aquatic sloughs represent an important link in the Everglades food chain.

Wet prairies are a conspicuous feature of WCA-1 and WCA-3, the Big Cypress National Preserve and the east and west margins of Shark River and Taylor sloughs (ENP), and the East Everglades Area. This community is also found in the sandy flatlands of WCA-3A's western tributary basins (C-139, L-28 Interceptor, Feeder Canal and L-28 Gap subbasins) as well immediately east of WCA-1 in the western C-51 basin.

In the mid-1950s wet prairies were common in WCA-2A, as well as in the western and southern sections of WCA-3A (Loveless, 1959b). Much of this habitat was lost as a result of stabilized water levels during the late 1960s and 1970s due to water storage activities within WCA-2A and the ponding of water in the south end of WCA-3A (Dineen, 1972). Several experimental drawdowns of WCA-2A have been initiated by the District in an effort to restore Everglades wet prairie habitat; however, these efforts have been only marginally successful (Worth, 1988). In 1989, the U.S. Army Corps of Engineers approved a District proposal to formalize a modified drawdown plan as the WCA-2A operational schedule.

Wet prairie habitat throughout south Florida has suffered alteration and destruction since 1900. More than 1,500 sq. mi. (3885 km^2) have been drained or destroyed including most of the wet prairies immediately west of the Atlantic coastal ridge. Estimates made in 1974 indicated that in Broward and Palm Beach counties alone, 80 percent of the wet prairies have been destroyed or altered (Birnhak and Crowder, 1974).

Ponds and Aquatic Sloughs. Ponds and aquatic sloughs represent the lowest elevations of the Everglades marsh, having deeper water levels and longer inundation periods than other Everglades wetland communities. Small ponds may occur in sloughs as solution holes in the limestone bedrock or may be formed by alligators in the peat soils. Ponds and aquatic sloughs occur throughout the Everglades with the largest pond-slough systems occurring in ENP (Shark River and Taylor sloughs) and portions of the northern Everglades (McPherson *et al.*, 1976). The dominant emergent vegetation of pond and slough systems are white water lily (*Nymphaea odorata*), floating heart *(Nymphoides aquatica)* and spatterdock (*Nuphar luteum* subsp. *macrophyllum*). Common submerged species include bladderwort *(Utricularia fliosa* and *U. biflora)* and the periphyton mat community.

Aquatic sloughs and ponds play important roles in the Everglades ecosystem. During the dry season ponds and sloughs serve as important feeding areas and habitat for Everglades wildlife. As the higher elevation wet prairies dry out, sloughs and ponds provide refuge for aquatic invertebrates and fish. The high concentration of aquatic life, in turn, makes ponds and sloughs important feeding areas for Everglades wading bird populations. When the marsh is reflooded, these areas serve to repopulate the marsh as water levels rise (Loveless, 1959). Small ponds created by alligators may often represent the only sources of food or water in the marsh during a major drought.

Tree Islands. (Bayhead, Swamp Forests) The freshwater, broadleaf, hydrophytic hardwood associations of the Everglades are commonly known as tree islands. Tree islands communities occur on the highest elevations encountered within the Everglades marsh. The name is descriptive of the isolated, emergent trees surrounded by lower stature marshes and are primarily comprised of swamp forest vegetation, although some small areas of relatively higher elevation support mesic, tropical hardwood vegetation. Many of the larger tree islands form an elongated tear drop shape, and are generally oriented with their main axes parallel to the direction of historical water flow. The bayhead or swamp forest is the most common forested wetland type in the Everglades marsh.

Typical trees which are co-dominant on tree islands are red bay (*Persa borbonia*), swamp Bay (*Magnolia virginiana)*, dahoon holly (*Ilex cassine*), pond apple (*Annona glabra*), and wax myrtle (*Myrica cerifera*). Other, less common species include willow (*Salix caroliniana*), Florida maple (*Acer floridium)* and strangler fig (*Ficus saurea*). A dense shrub layer is found beneath the canopy, comprised of cocoplum (*Chrysobalanus icacao)*, buttonbush (*Cephalanthus occidentalis*), leather leaf fern *(Acrostichum danaeifolium*), royal fern *(Osmunda regalis)*, cinnamon fern (*O. cinnamonea*), chain fern (*Anchistea virginica)*, bracken fern, (*Pteridium aquilinum*) and lizards tail, (*Saururus cernuus*).

Tree islands are important nesting and roosting sites for colonial birds (Givens, 1956) and are important habitat for Everglades deer and other terrestrial animals, especially during periods of high-water.

High water levels, peat fires and half-track (recreational) vehicles have had adverse impacts on Everglades tree island communities. In the central and south end of WCA-2A, tree islands have been nearly eliminated due to high water levels (Dineen, 1972; Worth, 1987). Severe peat fires have eliminated many tree islands in the central portion of WCA-3A. Invasion of exotic vegetation (principally melaleuca and *Schinus terebinthifolius*) is a major problem in WCA-1 and ENP (see Exotic and Nuisance Plant Species section of this Volume).

Willow Heads. Willow heads are found on sites with a history of severe soil disturbance, such as peat fires, lumbering, farming or alligator excavation as a result of nest building. Willow heads are thought to be pioneer species which invade freshly burned areas or other disturbed sites. In the northern WCAs, willow heads are most common adjacent to levees and interior canals were they form dense thickets. After repeated fires, willows often replace native vegetation on tree islands. In ENP, willow heads are common in the northern central areas of Taylor Slough (Olmstead, *et al.,* 1980). Large areas of willow are also found around the edge of Shark River Slough, where severe fires burned through tree island bayheads during the 1970s (Gunderson, 1987). Craighead (1971) reports that willow is more widespread now than in previous times due to changes in hydrology and impacts of dry season fires in ENP.

Cypress Forests. Cypress forests are a relatively minor feature of the WCAs and ENP. In the northern Everglades, cypress communities occur primarily along the fringe of the western portion of the study area (the L-28 Gap subbasin) and along the eastern perimeter of WCA-1. In the ENP, cypress occurs east and west of Long Pine Key. Two types of cypress forests, dome and prairie, occur within the study area. Both are dominated by pond cypress (*Taxodium ascendens).* Cypress forests include mixed swamp, cypress domes and strands, monospecific strands and dwarf or scrub cypress forests (Duever *et al.,* 1979). Understory vegetation includes button bush (*Cephalanthus occidentalis*), cocoplum (*Chrysobalanus icaco*), willow (*Salix* spp.), wax myrtle (*Myrica cerifera*), plus various species of swamp fern (family Polypodiaceae), marsh fleabane (*Pluchea foetida*), bromeliads (*Tillandsia* spp.) and orchids (family Orchidaceae) (Duever *et al.,* 1979). Submerged vegetation includes bladderworts and the periphyton community.

Cypress domes occur in bedrock depressions in the northern Taylor Slough area of ENP (Rintz and Loope, 1979) and are characterized by tall, dense stands of pond cypress with diameters up to 1.6 ft. (50 cm) and heights up to 80 ft. (25 m).

Cypress prairies of the Everglades were first described by Small (1932). These forests have also been described as dwarf, scrub or hatrack cypress (Craighead, 1971). Dwarf cypress trees attain heights of less than 16 ft. (5 m) and diameters of less than 8 inches (20 cm). The trees are widely spaced and include understory plants such as sawgrass, muhly grass, and other herbs and grasses.

Cypress forests are a sub-climax community that is maintained by fire. Fire reduces litter and peat accumulation and kills most invading hardwood species. In the absence of fire, peat accumulation raises ground elevations creating mesic conditions that are more favorable for invasion by hardwood species (Duever *et al.,* 1979).

4. Upland Vegetation.

Tropical Hardwood Forests. Tropical hardwood forests are primarily limited to ENP. These broadleaf, evergreen, upland forests are locally called hammocks. These forests are dominated by West Indian species and are the most diverse arboreal association in ENP. At least 120 hammocks are found in conjunction with the upland pine forest of Long Pine Key (Johnson *et al.*, 1983; Olmsted *et al.,* 1983). One of the largest tropical hardwood forests is Royal Palm Hammock, located at the edge of Taylor Slough and Long Pine Key. Royal Palm Hammock is noted for the emergent Royal Palm trees (*Roystonea elata)* (Small, 1916). This hammock was first protected in 1916 when 1,900 acres (769 ha) were set aside as Royal Palm State Park, which formed the nucleus of ENP. Tropical hardwood hammocks also develop on elevated outcrops on the upstream side of some tree islands. These sites have a history of habitation by native American Indians. Hammocks are also found in the saline zone of ENP (Craighead, 1971; Russel *et al.,* 1980).

The dominant overstory trees are live oak (*Quercus virginiana*), wild tamarind (*Lysiloma latisiliquum),* and gumbo limbo *(Bursera simaruba).* These trees attain heights of over 60 ft. (18 m) and diameters of over 6.6 ft. (2 m) (Olmsted *et al.*, 1981).

Other less common, tree species include sugar berry (*Celtis laevigata),* mastic *(Mastichodendron foetidissimum),* and, in the southern Everglades hammocks, mahogany (*Swietenia mahogani*).

A number of trees reach sub-overstory status and account for the tremendous stem density found in the hammocks. Included among these commonly found trees are: willow bustic (*Bumelia salicifolia),* lancewood (*Nectandra coriacea*), many species of stoppers (*Eugenia* spp.), pigeon plum (*Coccoloba diversifolia*), marlberry (*Ardisia escallonoides).* Few plants are found on the ground because of heavy shading by the dense canopy. Most consist of herbaceous epiphytic flora including vines, orchids, and bromeliads.

Hammocks that were recently burned or have histories of frequent past fires are in a successional, often scrubby phase. Hammocks with recurrent or severe fire damage are often colonized by Florida trema (*Trema floridana)* and bracken fern (*Pteridium aquilinum*). Some hammocks in the East Everglades that were subject to frequent and severe fires now support forests of Australian pine, an introduced species (Hilsenbeck *et al.,* 1979).

Upland Pine Forests. These upland plant communities occur primarily on rock out crops and sandy flatlands that are seldom flooded for more than a few weeks each year. Pine forests once covered about 2,000 sq. mi. (5,180 km^2) of south Florida, but have been reduced to less than half of their original extent (Birnhak and Crowder, 1974). Pine forests are found along the Atlantic Coastal Ridge, north of the Big Cypress National Preserve, and the sandy flatlands northeast of the WCAs (McPherson *et al.,* 1976). Characteristic plants of this upland habitat include slash pine (*Pinus elliotti* var. *densa*) and a variety of hardwood trees, shrubs, palms, grasses and other plants. Cabbage palms (*Sabal palmetto*) and saw palmetto (*Serenoa repens*) are also widely distributed in pine forest habitat. Grasses are often the dominant ground cover and include such species as beard grass (*Andropogon* spp.), wire grass (*Aristida stricta*) and panic grass (*Panicum* spp.) (McPherson *et al.*, 1976).

Fire is an important factor in controlling the species composition and species richness of understory vegetation. Without fire, hardwood species flourish and within 25 years, hardwood hammocks replace pine forest habitat (Alexander ,1967) In ENP, two types of pine forests were mapped by Johnson *et al.* (1983). Whether a pine forest has a low-stature understory or well-developed understory depends on an area's fire history. The most significant floristic feature of ENP rockland forests is the species richness of the low stature understory stratum. Loope *et al.* (1979) found 186 species in this association, making it the most diverse community in ENP.

5. Mangroves.

Approximately two thirds of the existing population of mangroves in the state are located within the boundaries of ENP, particularly in the White Water Bay/Shark River Slough areas and along the Gulf of Mexico. Within ENP, there are three species of mangrove: black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and red mangrove (*Rhizophora mangle*). These species are arranged in six community types: overwash, riverine, basin, hammock and scrub or dwarf mangrove.

Overwash communities, dominated by red mangroves are found principally on islands within Florida Bay. Fringe mangrove communities are typically thin stands along waterways and may contain all three species of mangroves in zones defined by tidal inundation. Riverine mangrove forests, possibly the largest community within ENP, are found along tidal rivers and creeks in the western portion of the park where red mangroves predominate along the banks, with other species found inland. Basin mangrove forests and hammock forests occur in areas where terrestrial runoff is channeled to tidal rivers of the coast. Basin forests are found in depressions and are dominated by black and white mangroves. Hammock forests occur in slightly higher elevations with all three species present. Scrub or dwarf forests are found on limestone and marl substrates within the eastern portion of ENP. This community type may be nutrient limited and contains all three species of mangrove.

Mangroves are important as a food source and habitat for fish and wildlife as well as to estuarine nutrient-cycling processes. Mangrove forests act as an important buffer, protecting coastal uplands from flooding due to storm surges from major storms or hurricanes. Mangrove prop roots allow for the colonization of algae, sponges, oysters, which in turn provide habitat for amphipods, isopods, shrimp and juvenile fish. Many bird species nest in the canopies of mangrove tress and feed in surrounding waters.

Mangrove leaf litter is the principal component of the detritus-based food web of these coastal estuaries. Riverine red mangrove leaf litter has been estimated to produce 2.4 gm (dry weight) of organic matter/m^2/day (Odum, 1970; Heald, 1969, 1971). As mangrove leaves are decomposed by microorganisms, they increase their nitrogen, protein, and caloric content (Heald, 1969). Tidal flow exports this material out of the mangrove forests into the estuary where it becomes utilized by a wide variety of juvenile fish and invertebrates. The detritus-based food chain supports an estimated 75-90 percent of the marine commercial and sports fish species found within south Florida estuaries (McPherson *et al.*, 1976). The juvenile phases of commercially important species of invertebrate such as shrimp, lobster and stone crabs rely heavily on mangrove detritus as a principal food source in their development. Odum *et al.* (1982) provides a discussion of the major values attributed to mangrove forests including substrate formation, water quality alterations, nutrient cycling, leaf litter production, and fish and wildlife habitat.

Davis (1940, 1943a) provided the first descriptions of mangrove forest distribution in south Florida. Heald (1969), Heald *et al.* (1974) and Odum *et al.* (1982) provided the first classic studies identifying the important role that mangrove communities play in estuarine aquatic productivity, nutrient cycling, leaf litter production, which provide habitat for fish and wildlife. The role of mangroves in peat formation has been investigated by Cohen and Spackman (1972) and Cohen and Davies (1989). Olmsted and Loope (1984) discussed their relative importance as land builders.

6. Exotic and Nuisance Plant Species.

Numerous exotic species have been brought into Florida for various purposes. Most of these species have not become established, and do not threaten native vegetation communities. Some, however, have escaped cultivation and are spreading in the wild. Contributing factors include south Florida's favorable climate and the virtual absence of natural population controls. Often these plants are characterized by a high reproductive potential and a rapid growth rate. Even though over 140 exotic plant species occur in the ENP only a few threaten to invade and displace native plants.

The National Park Service classifies exotic taxa as pest, potential pest, or innocuous for management purposes. The pest plants have large populations and pose the greatest threats of invasion. The woody plants that are well established in the Everglades and are invading the native habitats include Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina* spp.), melaleuca (*Melaleuca quinquenervia*), and shoebutton Ardisia (*Ardisia solanacea*) (La Rosa and Gunderson, in press). Problem non-woody plants include water hyacinth (*Eichhornia crassipes*), *Colubrina asiatica*, para grass (*Brachiaria mutica*) and *Reynaudia reynaudiana*.

Brazilian Pepper. Brazilian pepper (*Schinus terebinthifolius*), a native of Brazil, was introduced into Florida for ornamental planting (as Florida holly). It produces a large number of bright red berries which ripen between December and February (Ewel *et al.* 1982). Its fruit is edible to wildlife, and birds and small mammals are effective seed-dispersal agents. Brazilian pepper also can reproduce by shoots from its roots and runners (Duever *et al.*, 1979).

Brazilian pepper strangles and out-competes native vegetation. It produces dense stands of low-hanging, dead vegetation, and is fire-resistant. Brazilian pepper is an effective colonizer of disturbed areas, (Alexander and Crook, 1984), and prefers dry sites with a disturbed soil horizon. In the WCA planning area, it occurs primarily along canal banks, roadsides, and in abandoned farm fields.

Brazilian pepper, also poses one of the largest management problems in the ENP planning area because of its large populations and proven ability to invade a number of habitats. Until 1975, approximately 5,000 acres (2024 ha) in the southern part of Long Pine Key was farmed. This area, referred to as the "Hole-in-the-Donut", now supports woodlands that are dominated by Brazilian pepper, although shoebutton ardisia and para grass (*Brachiaria mutica*), have become dominant in pockets within the Brazilian pepper areas. The Hole-in-the-Donut includes the largest concentration of exotic plants in the ENP.

The farming practices of rock plowing and fertilization have altered the physical and chemical aspects of the substrate in the Hole-in-the-Donut area, allowing Brazilian pepper a competitive advantage over native species (Ewel *et al.*, 1982; Meador, 1977). The Brazilian pepper stand provides a large seed source for dispersal to other ENP communities. Brazilian pepper will establish in pinelands, and will dominate the understory if the stand is not burned, (Wade *et al.*, 1980). It can be controlled through the proper use of fire, (Loope and Dunevitz, 1981; Wade *et al.*, 1980). Brazilian pepper has also been found in disturbed, ecotonal areas of the mangrove forests (Mytinger and Williamson, 1987).

Australian Pine. Australian pine (*Casuarina equisetifolia*) includes at least three species. It is a native of Australia and is used in Florida as wind-breaks. Australian pine prefers dry areas. It is found most often in coastal areas; however, it can occur in spoil piles and in elevated areas such as canal banks and along road banks (Alexander and Crook, 1984).

Australian pine forms dense, monotypic stands with no understory. It is a brittle tree which easily snaps in high wind conditions. It is not considered to be fire-resistant (Alexander and Crook, 1984); however, it is reported to re-sprout after fire (Schomer and Drew, 1982). Australian pine spreads by wind-blown and bird-distributed seeds, as well as by root suckers (Alexander and Crook, 1984).

Australian pine,was the first major exotic plant recognized as invading ENP (Egler, 1952; Robertson, 1953). A pure stand of *Casuarina equisetifolia* developed on Highland Beach in ENP, but was successfully removed through cutting and burning (LaRosa and Gunderson, in press). Other stands of Australian pine are established in the southeastern panhandle of ENP (Klukas, 1969), replacing the bayhead species (Craighead, 1971). This process also occurred in the East Everglades in an area north and east of ENP, an area which may soon be incorporated into ENP.

Melaleuca. The melaleuca, or cajeput tree (*Melaleuca quinquenervia*), is native to Australia and was introduced to Florida in the early 1900's as an ornamental tree and possibly also as a commercial source of wood. This species tolerates both aquatic and terrestrial habitats often out-competing native plant species for space and light. It develops most rapidly in sawgrass areas with peat soils; however, it also occurs on marl and marly peat soils (Schomer and Drew, 1982). Prolific seed production, high growth rates, resistance to fire, lack of insect parasites, disease and competition from native plant species, further enhances melaleuca's ability to compete with native vegetation (Diamond, 1989).

Given the rapid growth of this species, melaleuca has the ability to invade and alter vast areas of the Everglades by replacing native tree islands and wet prairies with dense melaleuca stands. Mature stands (forests) of these tress often form dense monocultures which eliminate other species. These stands have limited wildlife value and are characterized by reduced species diversity (Austin, 1978; Schortemeyer *et al.,* 1980; Mazzotti *et al.,* 1981; Sowder and Woodall, 1986). It should also be noted that, because of its prolific flowering, melaleuca is considered to be important to beekeeping (Robinson, 1980).

Melaleuca has been identified as a potential threat to South Florida's future water supply. Evapotranspiration (E.T.) rates for melaleuca have been estimated to range from 3-6 times that of sawgrass (Hofstetter, R., personal communication, February 27, 1990, University of Miami, Miami, FL.). Woodall (1983) reports that melaleuca has a greater potential to trap rainfall in its paper-like bark, thereby reducing through-fall precipitation. Given these data, future spread of melaleuca throughout the Everglades has the potential to impact regional surface water supplies by replacing open sawgrass prairies with dense melaleuca forests, thus increasing ET rates. As of this writing, no direct field scale studies have been conducted within the Everglades which show a direct impact on the water table due to rainfall interception or increased E.T. rates induced by melaleuca.

The high oil content of melaleuca trees makes them highly volatile. As a result, crown fires often occur in dense forests of melaleuca and pose a serious threat to adjacent forests as well as urban areas and utility structures.

Melaleuca occurs throughout the WCAs. It is most prevalent in the tree island communities of WCA-1,WCA-2B and the East Everglades area, occurring to a lesser extent in WCA-2A , WCA-3A and WCA-3B (Melalueca Task Force, 1990). There is a large outbreak of melaleuca in the area immediately to the east of the WCAs, and this may be serving as an important seed source. Melaleuca often colonizes areas where the native vegetation has been disturbed or destroyed (e.g., after a severe fire) (Schomer and Drew, 1982).

Currently, no large stands of melaleuca are found in ENP. Isolated individuals are widely scattered throughout these wetland sites. Heavy infestations of melaleuca are found within WCA-2B (10,000 acres) and the eastern portion of the

East Everglades area (along Krome Avenue) and are expanding into surrounding disturbed wetlands. For a more detailed discussion concerning the magnitude of the problem, recommendations for control strategies and other technical data, the reader is referred to Volume IV, Appendix G. Draft Melaleuca Management Plan for South Florida (Melalueca Task Force, 1990).

Other Introduced Exotics. Other, less common, non-native plants in ENP are water hyacinth, shoebutton ardisia, and colubrina. Water hyacinth occurs in the L-67 extension canal in northern ENP areas. This floating aquatic plant has spread into adjacent marshes but does not appear to have yet displaced native species associations. Shoebutton ardisia occurs in and around the "Hole-in-the-Donut" and Royal Palm Hammock, where it was introduced as a landscape ornamental. *Colubrina* occurs in the mangrove areas of the ENP where it grows as a vine in mangrove tree tops (Olmsted *et al.*, 1981).

Control Programs for Terrestrial Exotic Species. Melaleuca invasion is a growing problem in the Loxahatchee National Wildlife Refuge, WCA-2B, WCA-3A north and portions of the East Everglades. There is concern that without adequate control, melaleuca will invade much of south Florida's wetlands, replacing native wetland flora, increasing evapotranspiration rates and adversely altering native wildlife habitats (Hofstetter, 1976; Wade *et al.*, 1980). Exotic species control efforts within the study area occur primarily within the WCAs. Melaleuca is the main problem species. In WCA-1, the Loxahatchee National Wildlife Refuge, the USFWS has implemented a melaleuca control program (Loxahatchee National Wildlife Refuge, 1988). This program specifies an integrated approach to melaleuca control, using a variety of chemical control agents, application techniques, and non-chemical control methods. The goal of this program is to minimize the spread of melaleuca, while slowly eliminating adult trees.

The USFWS with assistance by the SFWMD is administering an experimental melaleuca control program in WCA-1 in cooperation with the USFWS (Thayer, 1989). This program involves chemical treatment with Garlon 3A. As part of its levee maintenance program, the District removes Brazilian pepper and Australian pine from levee areas where they threaten bank stability (Baker, 1988). The FGFWFC does not have a program for exotic plant control. The FGFWFC is researching melaleuca control in Big Cypress National Preserve, and is coordinating with the District on research on melaleuca control within the WCAs (Ault, 1988). Recent interagency control programs, initiated by the Florida Exotic Pest Council, have eliminated melaleuca within a three-mile zone along the northern and eastern borders of the ENP and have mechanically removed many ardisia plants from the Hole-in-the-Donut and Royal Palm Hammock.

Aquatic Weeds. Floating and submersed aquatic weeds interfere with flood control and navigation in canals. Accumulations of aquatic weeds in canals can decrease flood control capacity and flow rates. Floating and uprooted aquatic plants interfere with the operation of pump structures. Aquatic weeds can also have adverse effects on ecological conditions. Exotic species can out compete native plants for biological resources, eventually replacing native vegetation. Aquatic weed infestations adversely affect fisheries by altering habitats and degrading water quality (e.g., lowering dissolved oxygen levels) (USDOI, 1972). The primary floating aquatic weed species found in south Florida canal systems are water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*). Hydrilla (*Hydrilla verticillata*) is the primary submersed aquatic weed species.

Several federal and state agencies are involved in aquatic weed control in south Florida. The USCOE is required by the 1899 Rivers and Harbors Act to remove plants that could interfere with navigation. The USCOE performs weed-control and provides funds to other agencies such as the U.S. Department of Agriculture (USDA) and the District to perform research and control (Fleming, 1987).

The DNR is the state agency responsible for coordinating all aquatic plant management activities within Florida (Florida Aquatic Weed Control Act, Ch. 369, Part II, F. S.). The DNR requires a permit for all aquatic weed control activities, except for biological controls. Biological control research is executed by the USDA. Permitting of the exotic grass carp (*Ctenopharyngodon idella*) is the responsibility of the FGFWFC. The DNR also reviews grass carp permit applications. The FGFWFC reviews all DNR aquatic weed control permit applications for non-tidal areas, according to Section 369.22(9), F. S. and an inter-agency agreement between DNR and FGFWFC (Fleming, 1987). The FGFWFC participates in development of the District's annual aquatic weed control work plan for DNR.

The SFWMD is responsible for maintaining operation and flow capacity of the south Florida canal system and for aquatic weed control in District-maintained canals within its 16-county jurisdiction (Fleming, 1987) The District is not responsible for canals of secondary drainage districts, and performs maintenance of federal navigable waterways under contract with USCOE. The SFWMD performs its weed-control program under an annual permit from the DNR (Thayer, 1989). The DER reviews all aquatic weed control permit applications for potential water quality impacts (DNR, 1989).

The USDA is responsible for aquatic plant control activities involving non-native biological agents (DNR, 1989). The USDA identifies and studies potential biological control agents, and performs the release of these biological controls. The USDA coordinates with the University of Florida (IFAS) on much of its research activities (Fleming, 1987). The NPS is also involved in aquatic weed control activities in the Everglades WCAs. As part of the Memorandum of Agreement among the USCOE, the SFWMD, and the NPS regarding the protection of water quality within the ENP, the NPS requires coordination on all chemical weed-control activities performed in the Park vicinity (Thayer, 1989).

F. WATER QUALITY CHARACTERISTICS OF EVERGLADES.

This discussion of Everglades water quality focuses on three primary issues--Historic Water Quality, Current Water Quality Conditions and Water Quality Criteria or Standards as the basis for water quality management.

1. Historic Conditions.

Water Quality within individual basins of the Everglades are described in detail in Section III of this volume which summarize available water quality information obtained from the EAA, WCAs, Eastern and Western basins, ENP, C-111 Basin and Florida Bay. This section is intended to provide a general overview of regional water quality characteristics, problems and trends.

Historic Conditions in the WCAs and ENP. Before construction of South Florida's regional water management system, water moved freely across the shallow Everglades, through more than 90 miles of sawgrass, wet prairies and open water sloughs, from Lake Okeechobee to the coastal estuaries of Florida Bay. Water moved as sheet flow, southward often at an almost imperceptible pace over this flat wetland terrain. Prior to 1950, relatively little information exists concerning historical water quality conditions within the Everglades. As a result, most of what we know today is derived from data on the soil nutrient content and species composition of the present day Everglades soils and vegetation. An approximation of what the historical water quality conditions were are based on the (a) historical sources of nutrients to the Everglades (primarily rainfall), (b) nutrient content and nutrient requirements of the vegetation (primarily sawgrass) which led to the formation of the region's rich organic soils, as well as (c) from water quality monitoring data collected from sites located deep within the interior of the Everglades that are thought to be unaffected by anthropogenic activity. Water quality information obtained from these sites sites are assumed to be representative of historic or natural background conditions (Davis *et al.*, 1987).

Low Nutrient Levels. Scientists have inferred that nutrient levels, primarily phosphorus and other micronutrients, in the water column of the pre-drainage Everglades were very low (Davis *et al.* 1987). The main source of nutrients was rainfall and infrequent flooding of Lake Okeechobee in the northern Everglades (Davis, 1943a; Parker *et al.*, 1955; Waller, 1975). The best data available indicate that today uncontaminated rainfall over south Florida has a total phosphorus concentration of 0.03 mg/l (Waller and Earl, 1975). Rainfall data collected elsewhere within southern Florida can, however, have a higher average concentration. Phosphorus levels in south Florida rainfall vary widely as a result of agricultural and urban atmospheric contamination (See Part IV, "Rainfall Water Quality in the WCAs").

A Nutrient Limited System. Aside from fire and infrequent frost, the unique vegetation of this ecosystem evolved in response to both low-nutrient water quality conditions and the seasonal fluctuations of water levels. Remote sites in the interior of the Everglades marsh, far removed from the influences of water control structures, and roads, provide the best estimates of pre-drainage Everglades water quality. At these interior sites, phosphorus concentrations in surface waters are extremely low. These low levels are due to limited input and rapid uptake and recycling by microorganisms. Soluble reactive phosphorus concentrations at these locations are typically at or below 0.004 mg/l, while average total phosphorus concentrations average near 0.01 mg/L. (During the wet season, inorganic nitrogen concentrations probably ranged between 0.01 and 0.02 mg/L.)

Coring (paleolimnologic) studies indicate that Lake Okeechobee has been eutrophic for the last four to five thousand years (Gleason and Stone, 1975, unpublished report). It is, therefore, reasonable to assume that during wet periods, when the lake spilled over its southern rim it provided pulsed flows of nutrients into the north end of the Everglades system and that these nutrients were transported a short distance south through the marshes by overland sheet flow. Another source of nutrient recycling in the system was fire. Seasonal migration, roosting and nesting of large numbers of wading birds may have also increased marsh nutrient levels in the vicinity of bird rookeries. Drought cycles also have undoubtedly released nutrients as a result of soil oxidation of Everglades organic peat soils. Thus, although localized recycling of stored nutrients, particularly phosphorus, and localized phosphorus inputs were present in the historical Everglades system the majority of the area evolved under low phosphorus loadings.

Historic Conditions in Coastal Estuaries. It is assumed that coastal estuaries of southeastern Florida and Florida Bay historically received more freshwater flow than occurs today. These bays and lagoons systems were probably predominantly fresh water during the wet season and brackish during the dry season. In spite of this seasonally increased flow, the estuaries probably received limited amounts of dissolved nutrients from upland flow because these materials were removed by marsh vegetation. The estuaries were nevertheless highly productive due the wide diversity of organisms that thrived in the low salinity environments that extended through much of Florida Bay.

2. Current Water Quality Conditions.

Water Quality in the EAA and Tributary Basins. This section provides a general overview of the EAA and other tributary basin water quality characteristics as they relate to historic and present conditions in the Everglades. Under current conditions a large portion of surface water flow that enters the Water Conservation Areas is derived from the EAA (approximately 23% or 1.0 million acre feet, see Part IV, "WCA Hydrologic Budget"). More comprehensive discussions of EAA canal water quality are presented in a later section of this document that deals with the EAA. Additionally water of poorer quality than that found within WCA interior marshes is discharged from tributary basins to the east and west. Water quality conditions and flows from these basins generally are not well documented. Descriptions of land use and water management of the eastern and western tributary basins are provided in the section of this report that deals with tributary basins. Inflow water volumes, flow-weighted nutrient concentrations, and nutrient loadings at pump stations S-5A, S-6, S-7 and S-8, are presented in Part IV of this plan entitled "WCA Nutrient Budget."

The marshes that historically occupied the EAA have been largely replaced with agricultural crops, primarily sugarcane, vegetables and sod. Agricultural drainage of these lands have resulted in subsidence of organic soils. Soil oxidation and the use of fertilizers have made the EAA a nutrient export region rather than a nutrient sink. The quality of water that leaves the EAA contains higher concentrations of nitrogen and phosphorus and other constituents than is generally found in local rainfall.

Sources of Water Quality Degradation. The EAA includes about 700,000 acres of rich organic soils that has largely been converted to intensively managed agriculture. Release of nutrients from the EAA soils occurs as the the result of periodic drying and oxidation of these organic soils by aerobic bacteria (soil subsidence). Once the soil is oxidized, large quantities of nitrogen and phosphorus are released and transported from these fields during subsequent rainfall events. Nutrients are carried from the fields through drainage ditches, water control structures and flood control pumps into EAA canals.

Water Quality in the EAA. Water draining the EAA farmlands contains low dissolved oxygen concentrations, high concentrations of nitrogen, phosphorus, chloride, sodium, trace metals, high color, high specific conductivity and occasional pesticide contamination (see Part II, section A.8 "Water Quality in EAA canals" and section B.5 "Previous Water Quality Studies Conducted in the WCAs").

Water Management Practices--Pumping Events. Water quality is generally worse during pumping events than during periods of no discharge. Highest concentrations of inorganic nitrogen were observed at pump station S-5A located within the eastern portion of the EAA. Nitrogen concentrations tended to be significantly higher at all stations during discharge events. Sampling station mean concentrations for chloride, color, nitrate, nitrite and ammonia were higher in the east portion of the EAA than in the west. Conductivity was highest at pump station station S-6 (1,412 umhos/cm during a pumping event and 1,259 umhos/cm with no discharge) and lowest at station S-8. Mean dissolved oxygen concentrations were highest at pump station S-8 (4.2 mg/l during discharge and 5.2 mg/l under no discharge) and lowest at pump station station S-6 (2.7 mg/L during discharge and 3.4 under no discharge).

Hydrologic Changes in the WCA's. Natural flow patterns of water have been drastically disrupted and altered as a result of drainage and development in the northern Everglades. With the exception of rainfall and flows into the system from the eastern Big Cypress Basin, all inflows and outflows to the Everglades are regulated by manmade water control systems. Today, water is routed quickly through a complex network of canals and impoundments, and flow is regulated by pumps and water control structures. Construction of the WCA impoundments has created a network of peripheral and transecting canals that act to shunt much of the water past the marshes and reduce or eliminate overland flow. Northern ends of WCA1 and 3A are over-drained while their southern ends have become inundated with standing water for much of the year (see Part I, section D "Hydrological Features".)

Water Quality Changes in the WCA's. Present water quality conditions in in some portions of the Everglades are dramatically different than conditions that existed at the turn of the century (1900s). Surface water presently entering WCA1 through pump stations S-5A and S-6, contains nutrient levels that are causing imbalances in the natural populations of aquatic flora and fauna in violation of Class III water quality standards. Surface waters entering Everglades National Park from WCA3A also contains excessive nutrients that are potentially harmful to its flora and fauna. Occasional exceedence of water criteria with respect to iron, chlorides, total dissolved solids and dissolved oxygen occur, primarily when water is being pumped into the WCA's. The primary water quality problem within the WCA's is the influx of nutrients--nitrogen and phosphorus. (see Part II, section B.5.,"Water Quality Characteristics of the WCAs).

Sources of Water Quality Degradation. Disruption of historical flow patterns due to regional drainage improvements (C&SF Project) and the development of agriculture south of Lake Okeechobee has caused major changes in the quality of water discharged south to the Everglades. Waters draining this agricultural region typically contain high concentrations of nutrients (nitrogen and phosphorus), dissolved solids (chloride, sodium and calcium carbonate), trace metals (copper, zinc, lead and iron) as well as occasional trace amounts of pesticides/herbicides all of which are in concentrations that are atypical of normal Everglades marsh water. Well over a dozen studies have indicated that water quality conditions have changed in the WCAs as a result of the drainage from agricultural and urban areas located to the north and east of the WCAs (see Part IV, "Previous Water Quality Studies Conducted in the WCAs). Dissolved solids, nutrients, chlorides, trace metals and pesticide concentrations have increased in waters originating within or passing through the Everglades Agricultural Area (EAA). Waters draining the EAA are of poor quality with concentrations of most parameters being the highest at WCA inflow points which drain this agricultural region. The EAA has been identified as the single most likely source of high nutrient concentrations discharged to the WCAs. Nutrient concentrations measured in water discharged from water management structures which drain the EAA are significantly higher than concentrations measured at interior WCA marsh sites. Average flow-weighted phosphorus concentrations at these discharge structures range from 0.10 to 0.25 mg/L and represent a 10-fold increase in nutrient levels as compared to interior WCA wetland phosphorus values (see Part II, section B.5,"Water Quality Characteristics of the WCAs).

WCA Marsh as a Nutrient Filter. A number of studies have identified the WCAs as a natural filtration system or nutrient sink which has a purifying or "kidney effect", reducing inorganic forms of nitrogen and phosphorus to background levels as these waters flow though the marsh. Much of these introduced substances are assimilated or incorporated into the sediments and marsh vegetation. Several studies have indicated that Everglades marsh vegetation has a limited capacity for nutrient uptake; other studies have documented ecological change within the marsh as a result of nutrient-enrichment. Data collected over the past decade indicate that nutrient-enrichment of the northern Everglades marsh has caused a number of ecological impacts to native Everglades plant communities. These changes are discussed briefly below and appear to be due to the combined effects of nutrient-enrichment, hydroperiod change, and fire. There is concern that if left unchecked, nutrient enrichment will spread to other areas of the WCAs (see Part II, section B.6,"Water Quality Degradation within the WCAs).

Impacts of Nutrient Enrichment on WCA Biota. Studies have correlated high nutrient concentrations with significant shifts in periphyton (algae) species composition, increased growth rates and other phenomena such as depleted oxygen concentrations and dominance of anaerobic bacteria. These studies indicate that the Everglades system is sensitive to relatively small increases in nutrient concentrations measuring in the hundreds of parts per million. The occurrence of high nutrient concentrations in waters passing through pump stations S-5A and S-6 and entering WCA1 is a cause for concern because these nutrient levels are causing imbalances in the natural populations of aquatic flora and fauna in violation of Class III water quality standards.

Periphyton. Periphyton is an important component of the Everglades food web and may play an important role in controlling surface water dissolved oxygen concentration, the formation of marls soils, and in the uptake of nutrients within the Everglades. In the Everglades, native periphyton communities appear to be extremely sensitive to even low levels of phosphorus added to the environment. Steward and Ornes (1975b) were first to document loss of the native periphyton mat as a result of phosphorus addition. This was later confirmed by Flora *et al.* (1987) in controlled nutrient dosing studies performed in ENP where the periphyton community was eliminated at orthophosphorus concentrations of 0.033 mg/l.

Results of experiments within WCA-2A by Swift and Nicholas (1987) indicated that increased phosphorus concentrations in marsh waters were associated with (1) changes in periphyton species composition, (2) reduced algal species diversity, (3) enhanced growth of pollution tolerant algae, and (4) increased periphyton phosphorus content. Native periphyton species were replaced by pollution-tolerant forms when total phosphorus concentrations in the water column exceeded 0.05 mg/l or higher. Diversity was low while the algal standing crop increased at the nutrient-enriched sites. In contrast, control stations that had low concentrations of nutrients were dominated by species indicative of natural conditions.

Macrovegetation. Control of cattails is considered to be an urgent problem because the rate of spread of these plants appear to have increased. Early studies indicated that the nutrient requirements of sawgrass are low compared to other wetland species (Steward and Ornes, 1975a,b). Sawgrass is considered a low nutrient status species which is competitive in low nutrient situations typical of the interior WCA marsh (Toth, 1988; Davis, 1991). Cattails are considered a high nutrient status species, relative to sawgrass, that are highly competitive in nutrient-enriched situations with long hydroperiods (Toth, 1988; Davis, 1991). Reducing the amount of nutrients that are discharged into the WCAs from surface water runoff should help minimize the possibility of any further spread of cattail.

Microbiology. Increased nutrient loading appears to first affect microbial populations (bacteria and fungi) that are responsible for the decomposition of leaf litter within the marsh. Anaerobic conditions (lack of oxygen) tend to dominate within the marsh leaf litter at nutrient-enriched sites as compared to aerobic and facultative microorganisms that predominate at non-enriched sites. Bacteria and fungi suspended within the water column were also found in higher densities at sites influenced by high concentrations of nutrients as compared to background sites. These changes in microflora tend to create prolonged, low or anoxic (zero dissolved oxygen) conditions within nutrient-enriched areas of the marsh (Reeder and Davis, 1983).

Water Quality In ENP. Average flow-weighted total phosphorus concentrations discharged into ENP from 1979-1988 were 0.011 mg/l for the four S-12 structures (see Part II, section B.5, "WCA Nutrient Budget"). Long-term water quality data has shown an increase in specific conductivity and major ion concentrations within Shark River Slough. These increases are due to changes from the natural sheet flow regime to one dominated by canal delivery (Flora and Rosendahl, 1981). No changes in metal concentrations have been observed while trace levels of pesticides have been occasionally detected in waters entering ENP. Current concerns focus on the possibility that water quality conditions upstream within the EAA and S-9 Basin will eventually impact the quality of water delivered to ENP via the L-67A canal.

Surface water entering the Park from the WCAs contains excessive nutrients that are being accumulated in the soils and sediments downstream of one or more Park water delivery structures. Once these soils and sediments are loaded with excess phosphorus, nuisance species that thrive on excess phosphorus are able to invade the marsh. The presence of these excessive nutrients is potentially harmful or injurious to animal and plant life in the Park. Accordingly, such nutrient-polluted water is, or is reasonably expected to be, a source of pollution in the Park. Considering the unique ecology of ENP, the nutrient concentrations in surface waters entering from WCA-3A are potentially harmful and should be reduced.

Water Quality in the East Everglades Basin. This discussion includes Northeast Shark River Slough (NESRS) and Taylor Slough (including the Frog Pond area. Water quality data for these areas are limited. Flora and Rosendahl (1982) and Waller (1982) report low nutrient concentrations within the basin. More current data collected by SFWMD from 1979-1988 indicate that flow-weighted total phosphorus concentrations at S-333 average 0.026 mg/l over the 10-year period of record. Highest concentrations (0.043 mg/l) occurred during the drought of 1985 as a result of routing water from Lake Okeechobee to western Dade county well fields through L-29 for water supply purposes.

Water Quality in the C-111 Basin. Water quality within the C-111 Canal at S-18C was rated as good to excellent. Total phosphorus values within the canal averaged 0.007 mg/l from 1985-1987 and were comparable to values recorded at interior marsh sites. C-111 Canal water contained moderate concentrations of dissolved minerals as compared to EAA drainage canals (Miami and Hillsboro canals) and exhibited low concentrations of nutrients (SFWMD 1990, in press). Canals draining urban and agricultural lands leading to the C-111 Canal had detectable levels of pesticides (e.g. atrazine and chlordane).

The most significant water quality impact observed within the basin has been the periodic removal of the S-197 structure from the mouth of the C-111 Canal to alleviate upstream flooding. This event released large amounts of freshwater into Manatee Bay, Barnes Sound and other surrounding estuarine areas causing severe impacts to marine biota.

Water Quality in Coastal Estuaries and Florida Bay. Changes that have occurred in coastal estuaries are due, in part, to such factors as an overall reduction of the amount of freshwater flow through the Everglades, effects of constructing levees and canals near the coast to provide drainage and flood protection and the maintenance of lower groundwater levels along the southeast coast. Although the amount of flow is disputed, the effects of this action are observed in the encroachment of mangroves north into the ENP in recent years; the replacement of freshwater marshes with saline marshes; and decline of coastal mangroves in areas that have been deprived of overland flow from uplands. Today many of these coastal estuaries, especially along the southeast coast and the central portion of Florida Bay, frequently experience hypersaline conditions during the dry season.

Continued residential development along North Key Largo will intensify problems of increased storm water runoff, septic tanks leachate and problems of nutrients and heavy metal contamination from marinas and live aboard vessels within Florida Bay and Barnes Sound.

3. Water Quality Standards and Criteria.

EAA. During periods when water is being pumped from the fields, and subsequently discharged in to the WCAs, dissolved oxygen concentrations were below the DER standard (5 mg/l) at S-5A, S-6, S-7 and S-8. Analyses by the FDER (1988) indicated that water quality was quite variable throughout the EAA. The L-8, West Palm Beach, Hillsboro, North New River and Miami canals, from Lake Okeechobee south to L-4 and across to L-8, exhibited generally poor water quality with extremely high nutrient concentrations and low dissolved oxygen (DO). Other problems in these waterways included abnormal biological oxygen demand, (BOD), bacteria, suspended solids, and presence of pesticides. Agricultural runoff and overflow or seepage from sugar mill retention ponds may also degrade the water quality in these canals.

WCAs. WCA-1 is classified by the state as a Class III water body and has been designated under Florida regulations as an Outstanding Florida Water (OFW). Class III waters are designated for use for recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife (Florida Administrative Code 17-3.081(1)). Degradation of water quality in water bodies classified as OFWs is not permitted except pursuant to Florida Administrative. Code 17-4.242(2) and (3), which provides a number of potential exceptions (Florida

Administrative Code 17-3.041(9)). The baseline for defining existing ambient water quality for WCA-1 is March 1, 1978 - March 1, 1979 (Florida Administrative Code 17-3.041 (16).

WCA-2 and WCA-3 are also classified by the state as Class III waters, but do not have OFW status. Maintenance of state water quality standards for Class III waters for dissolved oxygen, nutrient concentrations, biological oxygen demand (BOD), pH, bacteria, pesticides and macroinvertebrate diversity indices and other water quality parameters (chloride, specific conductance, iron, total dissolved solids) is recognized as a concern within the canals and perimeter marshes of the three WCAs.

Everglades National Park. Because of its status as a national park and its unique, water-dependent flora and fauna, ENP has been designated under Florida regulations as an Outstanding Florida Water (OFW) and has been proposed as an Outstanding National Resource Water (ONRW). Fla. Admin. Code 17-3.041(10),(17)(a),(18). The ONRW designation implements the federal antidegradation policy found in 40CFR Part 131.12. The ONRW represents the highest federal level of protection and is reserved for high quality waters of exceptional recreational or ecological significance. The proposed designation of ENP as an ONRW, however, does not become effective until the Florida Legislature enacts legislation that authorizes the protection and maintenance of ONRWs. Fla. Admin. Code 17-3.041(18)(b). State regulations establish for ONRWs a non-degradation standard with several narrow exceptions. Fla. Admin. Code 17-3.041(9).

This same non-degradation standard applies to OFWs; however, the exceptions to the OFW non-degradation standard differ. The OFW non-degradation standard presently applies in the ENP and those requirements that are not inconsistent with ONRW regulations will continue to apply after the enactment of appropriate ONRW legislation. Fla. Admin. Code 17-4.242(3)(c)7. ONRW regulations prohibit all discharges or activities that may cause degradation of water quality in ONRWs, while allowing discharges or activities that "clearly enhance" water quality in ONRWs. Fla. Admin. Code 17-4.242(3). The baseline for defining the existing ambient water quality in the Park, if designated as an ONRW, will be the period from March 1, 1976 to March 1, 1981, unless another period is otherwise designated. (Fla. Admin. Code 17-3.041(18)(d).

Existing Limitations and Monitoring Program. Existing water quality limitations for Everglades National Park are generally considered inadequate to protect the water quality and natural resources of the southern Everglades area. The criteria now in place were established in a memorandum of agreement by the ENP, the U.S. Army Corps of Engineers and the District in 1979 and later updated in 1984. The original numerical criteria were developed by ENP staff. The criteria were calculated from baseline water quality data for two inflow points that discharged water to the ENP from WCA-3A over a period of record from 1970 to 1978. Under the terms of the MOAs, the USCOE monitored four inflow stations to the ENP and the SFWMD monitored 12 stations within the tributary watersheds.

Water Quality Conditions. Four inflow points are sampled to determine compliance with the agreement. The parameters and standards of the current agreement include seven nutrients (nitrite, nitrate, organic nitrogen, inorganic nitrogen, total nitrogen, ortho-phosphorus and total phosphorus), six major ions (sodium, potassium, calcium, magnesium, chloride and ammonia), six physical and field parameters (dissolved oxygen, pH, specific conductivity, turbidity, color and alkalinity), seven metals (iron, mercury, cadmium, copper, zinc, arsenic and lead) and 21 pesticides or herbicides. On an average annual basis, the District generally has been in compliance with these criteria.

Adequacy of Existing Limitations. As stated in other sections of this document and in the Planning Document, the District has, in general, successfully delivered to ENP water of significantly higher quality than that defined in the MOA. A goal of the Everglades SWIM Plan is to ensure that the District continues to provide water of adequate and eventually improved quality to protect the biological integrity of ENP.

For many of the selected compounds, insufficient scientific data are available to determine the threshold levels above which Everglades communities could be damaged. Several of the current numerical criteria are considered to be inappropriate, failing to recognize normal background levels of dissolved oxygen and iron. The original MOA criteria were defined based on the quality of water entering the Park from WCA-3A. These same limitations were then applied to waters discharged into ENP from the C-111 basin. The criteria therefore do not adequately consider background water quality conditions that occur east of the ENP.

At the same time, other standards, especially for nutrients, are too high. Research by the District, ENP and others in the late 1970s and throughout the 1980s suggests that the nutrient levels that are allowable under the existing park criteria are potentially harmful and could cause extensive changes to bacteria, periphyton and macrophyte communities. Phosphorus is a major concern among the nutrients recognized by the current agreement.

G. THREATENED AND OR ENDANGERED SPECIES AND SPECIES OF CONCERN OR SPECIAL INTEREST.

Populations of many animal species have experienced declines throughout the Everglades. Factors that have led to population decreases include loss of habitat (as areas are developed for urban and agricultural use), intensive harvest and over use, altered hydroperiods, and fire patterns. Some wetland animal populations have been jeopardized by water management actions that have affected various aspects of their their life histories. Additional information concerning the distribution and status of these species is provided in the WCA and ENP sections of this plan.

Presently, 18 species of southern Florida animals that occur within the Everglades SWIM planning area have been designated as threatened or endangered by the USFWS and 12 more are under review to determine their status (Table 6). The Florida Game and Fresh Water Fish Commission (FGFWFC) has identified 25 species of threatened or endangered species in the planning area. Mammals on the state list include the Florida panther (*Felis concolor coryi)*, mangrove fox squirrel (*Sciurus niger avicennia)*, black bear (*Ursus americanus floridanus)*, Everglades mink (*Mustela vison evergladensis)*, and manatee (*Trichechus manatus latirostris)*. Only the panther and manatee are federally listed. Birds which may occur within the study area and are listed as endangered by the federal government include the Wood stork (*Mycteria americana)*, snail [Everglades] kite (*Rostrhamus sociabilis plumbeus)*, red-cockaded woodpecker (*Picoides borealis)*, Cape Sable seaside sparrow (*Ammospiza maritima mirabilis)*, Kirtland's warbler (*Dendroica kirtlandii)*, Bachman's warbler (*Vermivora bachmanii)*, peregrine falcon (*Falco peregrinus*), and southern bald eagle (*Haliaeetus leucocephalus leucocephalus)*.

Table 6. Endangered, Threatened, and Species of Special Concern in the Everglades Planning Area.*

	Species		State Design.	Federal Design.
Amphibians and Reptiles	American alligator	*Alligator mississippiensis*	SSC	T
	Loggerhead sea turtle	*Caretta caretta*	T	T
	Atlantic green turtle	*Chelonia mydas mydas*	E	E
	American crocodile	*Crocodylus acutus*	E	E
	Leatherback turtle	*Dermochelys coriacea*	E	E
	Indigo snake	*Drymarchon corais*	T	T
	Atlantic hawksbill turtle	*Eretmochelys imbricata imbricata*	E	E
	Gopher tortoise	*Gopherus polyphemus*	SSC	T
	Atlantic ridley turtle	*Lepidochelys kempii*	E	E
	Florida pine snake	*Pituophis melanoleucus megitus*	SSC	UR
	Gopher frog	*Rana areolata*	SSC	UR
Birds	Roseate spoonbill	*Ajaia ajaja*	SSC	
	Limpkin	*Aramus guarauna*	SSC	
	Burrowing owl	*Athene cunicularia*	SSC	
	Piping plover	*Charadrius melodus*	T	T
	White-crowned pigeon	*Columba leucocephala*	T	UR
	Kirtland's warbler	*Dendroica kirtlandii*	E	E
	Little blue heron	*Egretta caerulea*	SSC	
	Snowy egret	*Egretta thula*	SSC	
	Reddish egret	*Egretta rufescens*	SSC	UR
	Tricolored heron	*Egretta tricolor*	SSC	
	Swallow-tailed kite	*Elanoides forficatus*		UR
	White ibis	*Eudocimus albus*	SSC	
	Peregrine falcon	*Falco peregrinus*	E	T
	Southeastern kestrel	*Falco sparverius paulus*	T	UR
	Florida sandhill crane	*Grus canadensis pratensis*	T	
	American oystercatcher	*Haematopus palliatus*	SSC	
	Bald eagle	*Haliaeetus leucocephalus*	T	E
	Wood stork	*Mycteria americana*	E	E
	Osprey	*Pandion haliaetus*	SSC	
	Brown pelican	*Pelecanus occidentalis*	SSC	
	Red-cockaded woodpecker	*Picoides borealis*	T	E
	Crested caracara	*Polyborus plancus*	T	T
	Snail kite	*Rostrhamus sociabilis plumbeus*	E	E
	Least tern	*Sterna albifrons*	T	
	Bachman's warbler	*Vermivora bachmanii*	E	E
Mammals	Florida panther	*Felis concolor*	E	E
	Everglades mink	*Mustela vison evergladensis*	T	UR
	Florida mouse	*Peromyscus floridans*	SSC	UR
	Mangrove fox squirrel	*Sciurus niger avicennia*	T	UR
	West Indian manatee	*Trichechus manatus latirostris*	E	E
	Florida black bear	*Ursus americanus floridanus*	T	UR
Invertebrates	Florida tree snail	*Liguus fasciatus*	SSC	
	Bartram's hairstreak butterfly	*Strymon acis bartrami*		UR

E = endangered, T = threatened, SSC = species of special concern, UR = species presently under review.

* = FGFWFC, 1989 (List updated by M. Robson, FGFWFC, 1989)

The FGFWFC list includes the sandhill crane (*Grus canadensis*), crested caracara (*Polyborus plancus*), white-crowned pigeon (*Columba leucocephala*), and southeastern American kestrel (*Falco sparverius paulus*). The reptiles that occur on both lists are the eastern indigo snake (*Drymarchon corais couperi*), the loggerhead sea turtle (*Caretta caretta*), the Atlantic green sea turtle (*Chelonia mydas mydas*), the leatherback sea turtle (*Dermochelys coriacea*), the hawksbill sea turtle (*Eretmochelys imbricata imbricata*), the Kemps ridley (*Lepidochelys kempi*), and American crocodile (*Crocodylus acutus*). The American alligator (*Alligator mississippiensis*) is still listed as threatened by the federal government, but due to the increasing number of alligators in the state of Florida, the state has listed this species as one of special concern and resumed a limited hunting season beginning in 1988. The Florida Committee on Rare and Endangered Plants and Animals (FCREPA) lists additional animals not on official state or federal lists. Selected key species and groups which are directly affected by water management policies are discussed below.

Early naturalists found a number of mammals and birds which no longer are present in southern Florida. Layne (1984) lists the Florida red wolf (*Canis rufus floridanus*) as occurring in the state until the late 1800's. The Carolina Parakeet (now extinct) was present within the study area at the turn of the century.

1. Agency Responsibility.

In Florida, rare species of animals and plants may be protected by the federal endangered species program as well as by the state's endangered species program. Overall authority for the federal program rests with the USFWS. The federal program may be implemented by individual states after entering into an agreement with the USFWS. Florida is an agreement state and authority is shared within the state by the FGFWFC, DNR, and DACS. The FGFWFC is the state agency with constitutional responsibility for freshwater and upland wildlife species. The DNR is responsible for marine species. The DACS is the state agency responsible for threatened or endangered plants. In the federal program, species are listed as threatened or endangered under the authority of the Endangered Species Act of 1973. In the state program the protected species (threatened, endangered, and species of special concern) are identified by Florida Statute (3927.003-005 and 581.185-187). A list of all species protected under the federal and state threatened and endangered species program is maintained by the FGFWFC (1988).

The following discussion identifies species of wildlife that are designated threatened, endangered, or species of special interest or concern that may potentially occur within the Everglades SWIM planning area.

2. Birds.

Wading Birds. Robertson and Kushlan (1984) presented data to document the dramatic decline in the number of wading birds found in the interior wetlands of the Everglades. The most recent decline has been attributed to loss of suitable habitat due to drainage and development. The most abundant wading bird, both historically and currently is the white ibis, having a 1930's population count of 660,000 individuals (Robertson and Kushlan, 1984). Other birds which have declined in population are the egrets, small herons, and the wood stork.

Wood Stork. Wood storks (*Mycteria americana*) are listed as endangered on both the federal and state lists. The feeding habits and forage requirements of this species are intricately tied to specific hydrologic regimes that historically were provided by the natural Everglades system (Kushlan *et al.*, 1975). This species is generally considered to be a indicator organism for hydrologic regimes that sustain many wading bird populations and indicate a healthy food chain structure (Kushlan *et al.*, 1975; Ogden *et al.*, 1978; Loftus *et al.*, 1986). Populations of the stork in the both the WCAs and ENP have experienced a steady decline since the 1930's. A shift in the timing of nesting occurred in the 1960's followed by an accelerated decline in numbers during the 1970's and 1980's (Ogden, 1978; Ogden and Patty, 1982). Portions of this decline, particularly the steady early decline, have been attributed to the loss of wetlands in the southern Everglades region (Browder, 1976). More recently it has been recognized that the timing, rates of rise and recession, and total volume of water delivered to Everglades wetlands determine the success and location of wood stork nesting (Kushlan *et al.*, 1975; Ogden, 1978; Ogden and Patty, 1982).

Roseate Spoonbill. Spoonbills (*Ajaia ajaja*) are listed by the state as a species of special concern. Juveniles feed in the freshwater marshes of Lake Okeechobee and some parts of the Everglades. This species nests in coastal estuarine areas, primarily in Florida Bay (Powell *et al.*, 1989b). During the breeding season it feeds almost exclusively in the mangrove zone of the estuary (Powell and Bjork, 1989). This species serves as an indicator organism of the quality of the mangrove fringe habitat because the importance of this area to successful nesting (Powell *et al.*, 1989b; Powell and Bjork, 1989).

Reddish Egret. The reddish egret (*Egretta rufescens*) is listed on the state endangered species list as a species of special concern and is under review for inclusion on the federal list. This species feeds in coastal areas and has shown a decline that may be due to altered hydrologic conditions (Powell *et al.*, 1989b).

Small Herons. The tricolored heron (*Egretta tricolor*), little blue heron (*Egretta caerulea*), and snowy egret (*Egretta thula*) are listed on the state list of endangered species as species of special concern. They all utilize wetland habitat throughout Florida. These herons often nest together on islands or in woody vegetation over standing water, and feed primarily on small fish, and to a lesser extent on crustaceans and aquatic insects. These species are all affected by loss of wetland habitat (Robertson and Kushlan, 1974). Mixed colonies of these birds may have declined in the southern areas of the Everglades system (ENP) (Robertson and Kushlan, 1974; Kushlan and White, 1977a).

Limpkin. The limpkin (*Aramus guarauna*) is listed by the state as a species of special concern and occurs in freshwater wetlands throughout Florida. Because it feeds principally on aquatic invertebrates (snails) and is wholly dependent on wetland habitats and the quality of water and food available, the limpkin serves as an indicator organism for wetland quality. Limpkins are threatened by alteration and loss of wetlands.

Florida Sandhill Crane. The sandhill crane (*Grus canadensis pratensis*) is is long-legged wading and foraging bird that occurs in a variety of wetland and upland habitats. This species has a very low reproductive potential, and has been adversely affected by hunting, loss of habitat, and wetland drainage. Sandhill Cranes are often observed feeding in agricultural fields adjacent to WCA-1.

Raptors.

Snail [Everglade] Kite. The snail kite (*Rostrhamus sociabilis plumbeus*) is currently listed as endangered throughout its range on both state and federal endangered species lists. Populations of this raptor have fluctuated greatly since the species was first discovered in Florida (Bennetts *et al.*, 1988). During the wet period from 1981 to 1985, snail kite numbers in northern ENP increased markedly, only to decline after the 1985 drought. Rodgers *et al.* (1988) reported it is not accurately known whether the decreases in total snail kite numbers observed in the droughts of 1981 and 1985 was the result of kites dispersing from their normal range, increased mortality, decreased productivity, or a combination of factors. Forage requirements of this bird are severely restricted to the range of its principal prey, the apple snail. Kites forage in open ponded water and nest in wooded areas that are located over water to limit predation (Bennetts *et al.*, 1988). Success of the kite population is directly dependent on water management practices that provide for restricted drying rates, and availability of suitable nesting sites (Beissinger and Takekawa, 1983; Bennetts *et al.*, 1988)

Southern Bald Eagle. The bald eagle (*Haliaeetus leucocephalus leucocephalus)* is listed as threatened Florida and endangered by the federal government. Once common throughout Florida, the bald eagle is now absent or rare as a breeder along well-settled areas of the Florida coast. The bald eagle is primarily riparian (requiring water) and nests near water bodies in tall, living or dead trees. It is an opportunistic feeder, feeding primarily on fish, water birds, and turtles. Persistent pesticides and habitat destruction are major causes of population decline.

Swallow-Tailed Kite. The swallow-tailed kite (*Elanoides forficatus)* is listed as under review by the federal government. It is a winter migrant from South America but breeding pairs are found during the summer in Everglades National Park. It feeds by snatching lizards and snakes from the tops of trees, and consuming them in flight (George, 1972). This species is affected by loss of forage habitat.

Burrowing Owl. The burrowing owl (*Athene cunicularia)* is listed by the state as a species of special concern. It requires high, sandy ground with little vegetation and occurs throughout South Florida in spotty distributions. This species is primarily threatened because its preferred habitat is often under heavy pressure for development.

Audubon's Crested Caracara. Audubon's crested caracara (*Polyborus plancus audubonii)* is listed as threatened on both the Florida and federal list. It is restricted to dry prairie areas of south central Florida and is primarily limited to the extreme northwestern portions of the study area. Necessary habitat includes dry prairies with wet areas and scattered cabbage palms (*Sabal palmetto*). Decline of the caracara appears to be due to in large part to habitat conversion to developed land uses (Kale, 1978).

Arctic Peregrine Falcon. The Arctic Peregrine falcon (*Falco peregrinus tundrius)* is listed by both the state and federal government as endangered throughout its range. This species is a regular seasonal migrant through Florida and may overwinter in the southern tip of the state. Numbers of Arctic peregrine falcons have been drastically reduced by the use of chlorinated pesticides. Habitat for migration and overwintering in Florida is necessary for this species.

Other Species of Birds.

Cape Sable Seaside Sparrow. The Cape Sable Seaside Sparrow (*Ammospiza maritima mirabilis*) a subspecies of the seaside sparrow, was first discovered in the coastal prairies near Ochopee, Florida, and near Cape Sable (Werner, 1976). The habitat and biology of the bird were studied by Werner (1976), Taylor (1983), and Werner and Woolfenden (1983). Currently it inhabits the peripheral wetland prairies which border Shark River Slough, Taylor Slough, and the rocky glade lands (Bass and Kushlan, 1982a). These populations appear stable, and are estimated at 6,600 birds (Bass and Kushlan, 1982a).

White-crowned Pigeon. The white-crowned pigeon *(Columba leucocephala)* is listed by the state as threatened and is under review for inclusion on the federal list. It breeds and forages in mangrove forests and is threatened by habitat loss and a decrease in habitat viability.

Red-Cockaded Woodpecker. The red-cockaded woodpecker is listed as threatened by the state of Florida and endangered by the federal government. Historically, this woodpecker, (*Picoides borealis*), occurred throughout the state. It is the only woodpecker that nests in live trees, using mature to over-mature pines with advanced decay due to-the fungus, *Fomes pini*. This woodpecker has been adversely affected by forestry practices such as short rotation and harvesting of mature timber.

Warblers. Kirtland's warbler (*Dendroica kirtlandii*) and Bachman's warbler (*Vermivora bachmanii*) are listed by both the state and federal governments as endangered throughout their range.

3. Mammals.

Florida Panther. The historic range and habitat of the Florida panther *(Felis concolor coryi)* reflects that of its primary food sources, the white tail deer and the Florida Key deer. The panther's habitat has decreased significantly with only a small population numbering 30 to 50, primarily living on public lands (e.g., Big Cypress National Preserve and ENP) and adjacent agricultural lands. Loss of habitat is reported to be the major factor in the decline of this species (Belden, 1988). Additionally, road kills are a significant concern, including 13 panthers killed by traffic along Alligator Alley (U.S. 84) during the last decade. Due to low population numbers, inbreeding may be a cause of low birth rates in this species. The current range of the Florida panther includes ENP, the western areas of WCA-3A, and portions of the western borders of range land within the L-28 Gap, L-28 Interceptor, Feeder Canal and L-3 basins. Recent concerns have focused on the high levels of mercury found in Everglades raccoons, one of several prey items of the Florida Panther. Laboratory analysis of mercury levels in liver tissue of raccoons captured from nine different South Florida sites have been found to be as high as 24 parts per million (phone conversation 8/28/90 with Melody Roelke, Panther Recovery Project, FGFWFC). In 1989, the HRS and FGFWFC issued a public health advisory indicating that fish harvested from Everglades canals contained high levels of mercury (HRS, 1989). The diet of the Everglades raccoon (an omnivore) also contains fish (as well as a large number of other prey items including crayfish, molluscs, bird eggs, etc.) and exhibits high levels of mercury in both muscle and liver tissue comparison to Everglades deer (a herbivore) who feed mainly on grasses and shrubs. These observations suggest the possibility that raccoons may be bioaccumulating mercury as the result of eating mercury-contaminated fish and that a portion of the panther population may be consuming raccoon flesh containing high mercury concentrations. Moreover, the reported low birth rate of the Florida Panther may also be related to the chronic effects of long-term mercury contamination as noted in other feline populations (phone conversation 8/28/90 with Melody Roelke, Panther Recovery Project, FGFWFC). This link in the food chain has, as yet, not been confirmed. However in 1989, scientists detected 110 parts per million of mercury in the liver of a dead 4-year-old female panther found in ENP. It is stressed, however, that these data are very preliminary since raccoons make up the main part of a panther's diet in only a few areas of the Everglades.

Manatee. The total number of manatees, (*Trichechus manatus latirostris*) in Florida is estimated to be around 1,200, with 350 to 400 found on the Gulf Coast. Populations on the Atlantic and Gulf coasts appear to be isolated. This mammal is found in saltwater bays and estuaries. Reductions in the manatee populations are primarily due to power boat propellers, and habitat destruction (Pritchard 1978). Manatees have also been crushed in locks or water control structures, primarily the coastal structures in Dade and Broward counties. In response to this problem the SFWMD has made operational changes to these coastal structures to reduce the likelihood of manatees becoming trapped or damaged. In a survey of manatee populations on the west coast of Florida, Irvine *et al.* (1981) determined that ENP was the southern limit of the population's range. Manatees have been noted entering Whitewater Bay during winter months.

Everglades Mink. The Everglades mink (*Mustela vison evergladensis*) is restricted to fresh water wetlands. Mink has been observed in Big Cypress National Preserve, the Everglades, and around Lake Okeechobee (Layne, 1976; Smith and Cary, 1982). It is indicated that this species has a fairly clustered distribution, being found primarily in the southern portions of WCA-3A. The mink is affected by loss of wetland habitat, highway mortality, and changes in water quality and quantity.

Florida Mouse. The Florida mouse (*Peromyscus floridanus*) occurs in relatively xeric conditions, in close association with the gopher tortoise (*Gopherus polyphemus*) and is threatened primarily by land development (e.g.. citrus production and pine plantations). Additionally, habitat is lost in areas where fire protection has caused conditions that are too dense and shady for optimal mouse habitat.

Mangrove Fox Squirrel. The preferred habitat of the mangrove fox squirrel (*Sciurus niger avicennia*) is hammocks,and pine and cypress forests. Squirrel populations are being reduced due to loss of habitat.

Florida Black Bear. The range of the black bear (*Ursus americanus floridanus*) has been greatly reduced in southern Florida. It is now restricted to small populations near large swamps, such as the Big Cypress National Preserve. Habitat destruction and persecution by cattlemen and beekeepers appear to be the principal reasons for the species' decline (Schemnitz, 1974; Brady and Maehr, 1985).

4. Amphibians and Reptiles.

American Crocodile. The American crocodile (*Crocodylus acutus*) can be found from southern Biscayne Bay, west along the mainland, and south along Key Largo. Preferred habitats are coastal mangrove swamps, salt and brackish water bays, and creeks (Behler, 1978). The primary nest sites in Florida Bay are in the edge of hardwood thickets at the heads of small sand beaches or on relatively high marl banks of narrow coastal creeks (Ogden, 1978a). The crocodile is the dominant carnivore in these habitats and is presumed to play an important role in nutrient cycling and ecosystem dynamics (Behler, 1978). Past exploitation and habitat loss have resulted in a decline in numbers of crocodiles. The crocodile is currently listed as endangered on both Federal and State lists.

American Alligator. The alligator, (*Alligator mississippiensis*), is well distributed in wetland habitats throughout the state. Hunting for alligator hides greatly reduced this reptile's population across much of its former range by the late 1960s. In 1969, the Lacey Act was amended to prohibit the interstate movement of illegal alligator skins. The state of Florida made the sale of alligator products illegal in 1972. Further protection was provided under the Endangered Species Act of 1973 (Hines and Percival, 1986). The alligator is apparently a very adaptive and resilient species. Since receiving protected status, its numbers have increased throughout the state. The alligator's continued recovery led the FGFWFC to initiate an annual alligator harvest in 1988 (Woodward *et al.*, 1987).

Water management impacts on the American alligator have been identified by Kushlan (1987), who correlated dry season flood releases with alligator nest flooding and resultant egg mortality. Drainage of marshes, such as those in Northeast Shark Slough and East Everglades, appears to result in reduced carrying capacity (Fleming, in prep.). Lower densities of alligators in degraded marshes has an impact on other aquatic species because the dry season shelter that the alligators create in the form of 'gator holes are less available.

Sea Turtles. Marine turtles were once common along the coast of Florida. Due to development of beaches, degradation of estuaries, nest poaching, and mortality due to capture in fish and shrimp nets, four of the five species are classified as endangered. The loggerhead turtle, (*Caretta caretta caretta)*, is classified as threatened. Any of the sea turtle species may use Florida Bay as foraging habitat. Kemp's Ridley sea turtle (*Lepidochelys kempii*) has been reported as migrating through the area (Robertson, 1989; McVey and Wibbels, 1984). Nesting loggerheads have been documented in ENP (Holden, 1964, 1965; Klukas, 1967; Davis and Whiting, 1977). Davis and Whiting (1977) reported between 600 and 1,200 nests on Cape Sable beaches in 1972 and 1973. Nesting has also occurred on Sandy Key, Shark Point, Highland Point, Lostmans Beach, Hog Key, Plover Key, North Plover Key, Turkey Key, New Turkey Key, Pavilion Key and Rabbit Key. Juvenile green turtles are know to regularly utilize Florida Bay (South Florida Research Center unpublished data).

Eastern Indigo Snake. This snake (*Drymarchon corais couperi)* is widely distributed throughout the American tropics. It occurs in association with the gopher tortoise, and has been impacted by loss of habitat and by over collection.

Gopher Tortoise. Scattered populations of gopher tortoises (*Gopherus polyphemus*), occur in xeric habitats in Florida. This tortoise digs burrows up to 30 ft (9 m) in length that can be co-inhabited by perhaps three dozen other species. Gopher tortoise populations have declined due to loss of habitat and collection for food.

Florida Pine Snake. This snake (*Pituophis melanoleucus mugitus)*, occurs in xeric habitats in Florida. It is found in association with the gopher tortoise, and is adversely affected by loss of habitat (Ashton and Ashton, 1981; Carr, 1940).

5. Invertebrates.

Tree Snail. The tree snail (*Liguus* spp), is identified as a Species of Special Concern. Fifty-eight varieties of this tree snail, each with a unique color pattern, occur in the tree islands and hammocks throughout the Everglades, with some varieties present in only one or two hammocks. Because of the beauty of their shell, this species of snail has been a prime target for collectors. For this reason, *Liguus* is a protected species within ENP.

Bartram's Hairstreak Butterfly. This species of butterfly, (*Strymon acis bartrami)* is classified as a species under study by the USFWS. It occurs in the understory of slash pine forests in southern Dade and Monroe counties.

6. Threatened or Endangered Plant Species.

A number of rare, threatened and or endangered species of plants exist within the Everglades SWIM planning area. The most notable of these are epiphytic species;

bromeliads, orchids, and ferns which, because of their beauty, have long been the target of collectors. Bromeliads and orchids inhabit the dimly lit tropical hardwood hammocks, tree islands and cypress heads, with a few species adapted to full sunlight. Fire, loss of habitat, and poaching by amateur and commercial collectors has reduced the number of species in the wild. **Table 7** lists threatened and or endangered plant species that may occur in the Everglades SWIM planning area.

H. REGIONAL ECONOMICS.

The following information was derived from Florida Statistical abstracts (Shoemaker *et al.*, 1988) for the year 1986 (the most recent year for which data have been compiled) unless otherwise noted. The South Florida economy is based on services, agriculture, and tourism. The service industry is associated with the over 65 population which constitutes nearly one-fourth of the residents of Broward and Palm Beach Counties and sixteen percent of Dade's population. These individuals have incomes independent of employment and require additional medical, financial, and household services.

Tourism is also an important component of the regional economy. There are 93,479 hotel and motel rooms in the region, and 762,000 restaurant seats. Annual payroll for the hotel and motel, and amusement categories is approximately $70,561,000 dollars. Total regional earnings from employment is $35 billion. Retail trade and services account for nearly half of the employment of the region, and $14.5 billion of earnings per year (Shoemaker *et al.*, 1988).

Related to tourism are the golf courses in the region which use a great deal of irrigation water. There are 207 golf courses in the region, 113 in Palm Beach County alone. No data are available on the amount of water used to irrigate all of these courses because many are on individual wells. Studies are underway to accurately measure this withdrawal. According to the National Golf Foundation, a course open to the public generates between $1.5 to 2 million a year and a private club generates about the same. Applying this factor to the courses in the region shows about $362 million a year is generated in gross income by golf courses.

Agricultural production in the region, excluding the Everglades Agricultural Area, totaled $450 million in 1987/88. Virtually all the production is crops including winter vegetables, tropical fruits and vegetables, citrus and nursery crops. Agriculture generates a great deal of financial value, yet this sector does not account for a significant proportion of employment or earnings.

Census data indicate that Labor force participation rates in Dade and Broward counties increasing slightly between 1970 and 1980. Palm Beach County was virtually unchanged. Despite the large over-65 population in the region, the rates are quite close to the state's average. The rates are 55% for Broward, about Florida's overall participation rate; 61% for Dade, the region's highest; and 53% for Palm Beach. Unemployment for the region has been fairly low in the 1980's. The 1985 figure for Broward was 4.8%, 7.1% in Dade, and 6.2% in Palm Beach. The State's unemployment rate for this period was 6%, nationally it was 7.1%. Per capita income in all three counties as of 1985 was greater than the state average and has increased considerably since 1979. Palm Beach is the highest at $14,260, Broward is $13,578, and Dade is $11,278. Dade's per capita income showed the lowest rate of increase (465) in the six year period; Broward's grew by 58% and Palm Beach's by 60%.

The southern counties have grown rapidly in population over the last twenty years, and have increased their economic diversity. Manufacturing, prior to the 1970's, was a fairly insignificant component of regional employment. Now it

Table 7. Endangered, Threatened, and Commercially Exploited Plant Species Under Review in the Everglades Planning Area(FGFWFC, 1989).

Common Name	Scientific Name	State Design.	Federal Design.
Paurotis palm	*Acoelorrhaphe wrightii*	T	
Golden leather fern	*Acrostichum aureum*	E	
Giant leather fern	*Acrostichum danaeifolium*	T	
Fragrant maidenhair fern	*Adiantum melanoleucum*	E	
Maidenhair fern (unnamed)	*Adiantum tenerum*	T	
Pine fern	*Anemia adiantifolia*	T	
Blodgett's wild-mercury	*Argythamnia blodgettii*		UR
Ebony spleenwort	*Asplenium platyneuron*	T	
Plumose aster	*Aster plumosus*		UR
Mosquito fern	*Azolla caroliniana*	T	
Pine pink	*Bletia purpurea*	T	
Long-tailed spider orchid	*Brassia caudata*	T	UR
Rattail orchid	*Bulbophyllum pachyrrhachis*	E	
Many-flowered grass pink	*Calopogon multiflorus*	T	
Pale grass pink	*Calopogon pallidus*	T	
Grass pink (unnamed)	*Calopogon tuberosus*	T	
Strap fern (unnamed)	*Campyloneurum phyllitidus*	T	
Powdery catopsis	*Catopsis berteroniana*	E	
Air plant (unnamed)	*Catopsis floribunda*	E	
West Coast prickly apple	*Cereus gracilis*	E	UR
Dildoe cactus	*Cereus pentagonus*	T	
Southern lip fern	*Cheilanthes microphylla*	T	
Satinleaf	*Chrysophyllum olivaeforme*	E	
Silver palm	*Coccothrinax argentata*	C	
Coconut palm	*Cocos nucifera*	T	
Geiger tree	*Codia sebestena*	E	
Okeechobee gourd	*Cucurbita okeechobeensis*	E	UR
Cowhorn orchid	*Cyrtopodium punctatum*	E	
Two-spike finger grass	*Digitaria pauciflora*		UR
Narrow-leaved Carolina scalystem	*Elytraria carolinensis* var. *angustifolia*		UR
Dollar orchid	*Encyclia boothiana*	E	UR
Shell orchid	*Encyclia cochleata*	T	
Butterfly orchid	*Encyclia tampensis*	T	
Dingy-flowered epipendrum	*Epidendrum anceps*	T	
Unbelled epidendrum	*Epidendrum difforme*	T	
Night-scent orchid	*Epidendrum nocturnum*	T	
Rigid epidendrum (=strobiliferum)	*Epidendrum rigidum*	T	
Longleaf cup grass	*Eriochloa michauxii*		UR
Beach creeper	*Ernodia littoralis*	T	
Low erythrodes	*Erythrodes querceticola*	T	
Redberry ironwood	*Eugenia confusa*	T	
Wild coco	*Eulophia alta*	T	
False coco	*Eulophia ecristata*	T	
Garber's spurge	*Euphorbia garberi*	E	T
Porter's hairy-podded spurge	*Euphorbia porteriana* var. *porteriana*		UR
Porter's broom spurge	*Euphorbia porteriana* var. *scoparia*		UR
Narrow-leaf milkpea	*Galactia pinetorum*		UR
Orchid (unnamed)	*Galeandra beyrichii*	T	
Polypody fern (unnamed)	*Goniophlebium triseriale*	T	
Wild cotton	*Gossypium hirsutum*	E	
Orchid (unnamed)	*Govenia utriculata*	T	

E-endangered, T-threatened, UR-under review, C-commercially exploited.

Table 7. Endangered, Threatened, and Commercially Exploited Plant Species Under Review in the Everglades Planning Area*(Continued).

Common Name	Scientific Name	State Design.	Federal Design.
Fuch's bromeliad	*Guzmania monostachia*	E	
Rein orchid (unnamed)	*Habenaria odontopetala*	T	
Michaux's orchid	*Habenaria quinquesta*	T	
Water spider orchid	*Habenaria repens*	T	
Orchid (unnamed)	*Harrisella porrecta*	T	
Manchineel	*Hippomane mancinella*	T	
Broad-leaved spider lily	*Hymenocallis latifolia*		UR
Inkwood	*Hypelate trifoliata*	T	
Krug's Holly	*Ilex krugiana*	T	
Delicate ionopsis	*Ionopsis utricularioides*	E	
Florida quillwort	*Isoetes flaccida*	T	UR
Pineland clustervine	*Jacquemontia curtissii*	E	UR
Joewood	*Jacquinia keyensis*	T	
Catesby lily	*Lilium catesbaei*	T	
Carter's small-flowered flax	*Linum carteri* var. *carteri*		UR
Holly fern	*Lomariopsis kunzeana*	T	
Trinidad macradenia	*Macradenia lutescens*	T	
Florida malaxis	*Malaxis spicata*	T	
Polypody fern (unnamed)	*Microgramma heterophylla*	T	
Simpson's stopper	*Myrcianthes fragans* var. *simpsonii*		UR
Boston fern (unnamed)	*Nephrolepis biserrata*	T	
Burrowing four-o'clock	*Okenia hypogaea*	E	
Coot Bay dancing lady	*Oncidium carthagenese*	T	UR
Florida oncidium	*Oncidium floridanum*	T	
Mule-ear orchid	*Oncidium luridum*	T	
Hand adder's tongue fern	*Ophioglossum palmatum*	E	UR
Twistspine prickly pear	*Opuntia compressa*	T	
Prickly pear (unnamed)	*Opuntia stricta*	T	
Royal fern	*Osmunda regalis*	C	
Everglades peperomia	*Peperomia floridana*	E	UR
Pepper (unnamed)	*Peperomia humilis*	E	
Florida peperomia	*Peperomia obtusifolia*	E	
Everglades knotweed	*Persicaria paludicola*		UR
Golden polypoda	*Phlebodium aureum*	T	
Florida five-petaled leaf flower	*Phyllanthus pentaphyllus floridanus*		UR
Elliot's sticky ground cherry	*Physalis viscosa* var. *elliotii*		UR
Snowy orchid	*Platanthera nivea*	T	
Orchid (unnamed)	*Pleurothallis gelida*	T	
Boykin's few-leaved milkwort	*Polygala boykinii* var. *sparsifolia*	UR	
Big yellow milkwort	*Polygala rugelii*	T	
Tiny milkwort	*Polygala smallii*	E	E
Polypody fern (unnamed)	*Polypodium plumula*	T	
Ghost orchid	*Polyrrhiza lindenii*	E	
Pale-flowered polystachya (=concreta; =extinctoria)	*Polystachya flavescens*	T	
Shadow witch	*Ponthieva racemosa*	T	
Orchid (unnamed)	*Prescottia oligantha*	T	
Whisk fern	*Psilotum nudum*	T	
Ladder brake fern	*Pteris longifolia*	T	
Giant brake fern	*Pteris tripartita*	T	
Brake fern (unnamed)	*Pteris vittata*	T	
Mistletoe cactus	*Rhipsalis baccifera*	E	UR
Brown-haired snoutbean	*Rhynchosia cinerea*		UR

E-endangered, T-threatened, UR-under review, C-commercially exploited, Source;FGFWFC, 1989.

Table 7. Endangered, Threatened, and Commercially Exploited Plant Species Under Review in the Everglades Planning Area (Continued).

Common Name	Scientific Name	State Design.	Federal Design.
Florida royal palm	*Roystonea elata*	E	UR
Bahamia sachsia	*Sachsia bahamensis*	E	
Water spangles	*Salvinia rotundifolia*	T	
Inkberry	*Scaevola plumieri*	T	
Florida autumngrass	*Schizachyrium rhizomatum*		UR
Tropical curly-grass fern	*Schizaea germanii*	E	UR
Armored spikemoss	*Selaginella armata*	T	
Red-margined mallow	*Sida rubromarginata*		UR
Parsley fern	*Sphenomeris clavata*	T	
Florida ladies' tresses	*Spiranthes brevilabris* var *floridana*	T	
Fragant ladies' tresses	*Spiranthes cernua* var. *odorata*	T	
Ladies' tresses (unnamed)	*Spiranthes costaricensis*	T	
Ladies' tresses (unnamed)	*Spiranthes cranichoides*	T	
Lace-lip ladies' tresses	*Spiranthes laciniata*	T	
Leafless beaked orchid	*Spiranthes lanceolata* var. *lanceolata*	T	
Long-lip ladies' tresses	*Spiranthes longilabris*	T	
Florida Keys ladies' tresses	*Spiranthes polyantha*	E	UR
Giant ladies' tresses	*Spiranthes pracox*	T	
Spring ladies' tresses	*Spiranthes vernalis*	T	
Slender queen's delight	*Stillingia sylvatica tenuis*		UR
Bay cedar	*Suriana maritima*	E	
West Indian mahogany	*Swietenia mahogani*	T	
Halberd fern (unnamed)	*Tectaria heracleifolia*	T	
Halberd fern (unnamed)	*Tectaria lobata*	T	
Tetrazygia	*Tetrazygia bicolor*	T	
Downy shield fern	*Thelypteris dentata*	T	
Aspidium fern (unnamed)	*Thelypteris interrupta*	T	
Aspidium fern (unnamed)	*Thelypteris kunthii*	T	
Creeping fern	*Thelypteris reptans*	T	
Aspidium fern (unnamed)	*Thelypteris reticulata*	T	
Aspidium fern (unnamed)	*Thelypteris sclerophylla*	T	
Wild pine (unnamed)	*Tillandsia balbisiana*	T	
Wild pine (unnamed)	*Tillandsia circinata*	T	
Wild pine (unnamed)	*Tillandsia fasciculata*	C	
Twisted air plant	*Tillandsia flexuosa*	T	
Wild pine (unnamed)	*Tillandsia polystachia*	T	
Wild pine (unnamed)	*Tillandsia setacea*	T	
Giant wild pine	*Tillandsia utriculata*	C	
Wild pine (unnamed)	*Tillandsia valenzuelana*	T	
Filmy fern (unnamed)	*Trichomanes punctatum*	T	
Florida gramagrass	*Tripsacum floridanum*		UR
Worm-vine orchid	*Vanilla barbellata*	E	
Scentless vanilla	*Vanilla inodora*	T	
Leafy vanilla	*Vanilla phaeantha*	T	
Coastal vervain	*Verbena maritima*		UR
Shoestring fern	*Vittaria lineata*	T	
East Coast coontie	*Zamia umbrosa*	C	

E-endangered, T-threatened, UR-under review, C-commercially exploited; Source;FGFWFC, 1989.

accounts for 175,468 jobs and is nearly twice the percentage share of construction (98,416 jobs), which once considered one of the major South Florida industries. This economic diversity has insulated South Florida from one recession in the early 1980's. As the area becomes home to many kinds of businesses, it will become increasingly able to withstand national economic upheavals that may affect the rest of the Nation.

Water availability and quality are critical to support new residents, which fuels the burgeoning service, retail trade, and financial industries, and to the tourist industries, on which so many jobs depend. Agricultural production depends on water availability and land use restrictions for agricultural protection as land prices become ever more lucrative to the farmer, particularly in these coastal sections. Residential water use from public supply in 1985 for the three counties was 674 MGD. Per capita usage in the counties was 170 in Broward, 194 in Dade, and 212 in Palm Beach. An estimated, 22 MGD was withdrawn by domestic self-supplied users.

Housing and Land Use. These counties have seen the development of a number of bedroom communities, particularly in Broward county, that have no intrinsic economic activity except to provide housing in pleasant surroundings away from the congestion of Ft. Lauderdale, West Palm Beach or Miami. In addition, the retired population wants to be near services but has no need to be close to employment centers. In 1986, the proportion of land uses in the southern counties by value was overwhelmingly residential and had a total valuation of $94,087.26 million. The value of agricultural land was $2,078.84 million. Part of this lower valuation is based on the way agriculture land is assessed--at a lower rate than residential--rather than to lower actual land value. Of the 3.3 million acres in the three county area, about 25% is in farms. Residential areas in 1988 had approximately 1.8 million dwelling units of which 50% were multifamily, 46% were single family and 4% were mobile homes.

This Page Intentionally Left Blank

III. BASIN MANAGEMENT UNITS

A. EVERGLADES AGRICULTURAL AREA (EAA).

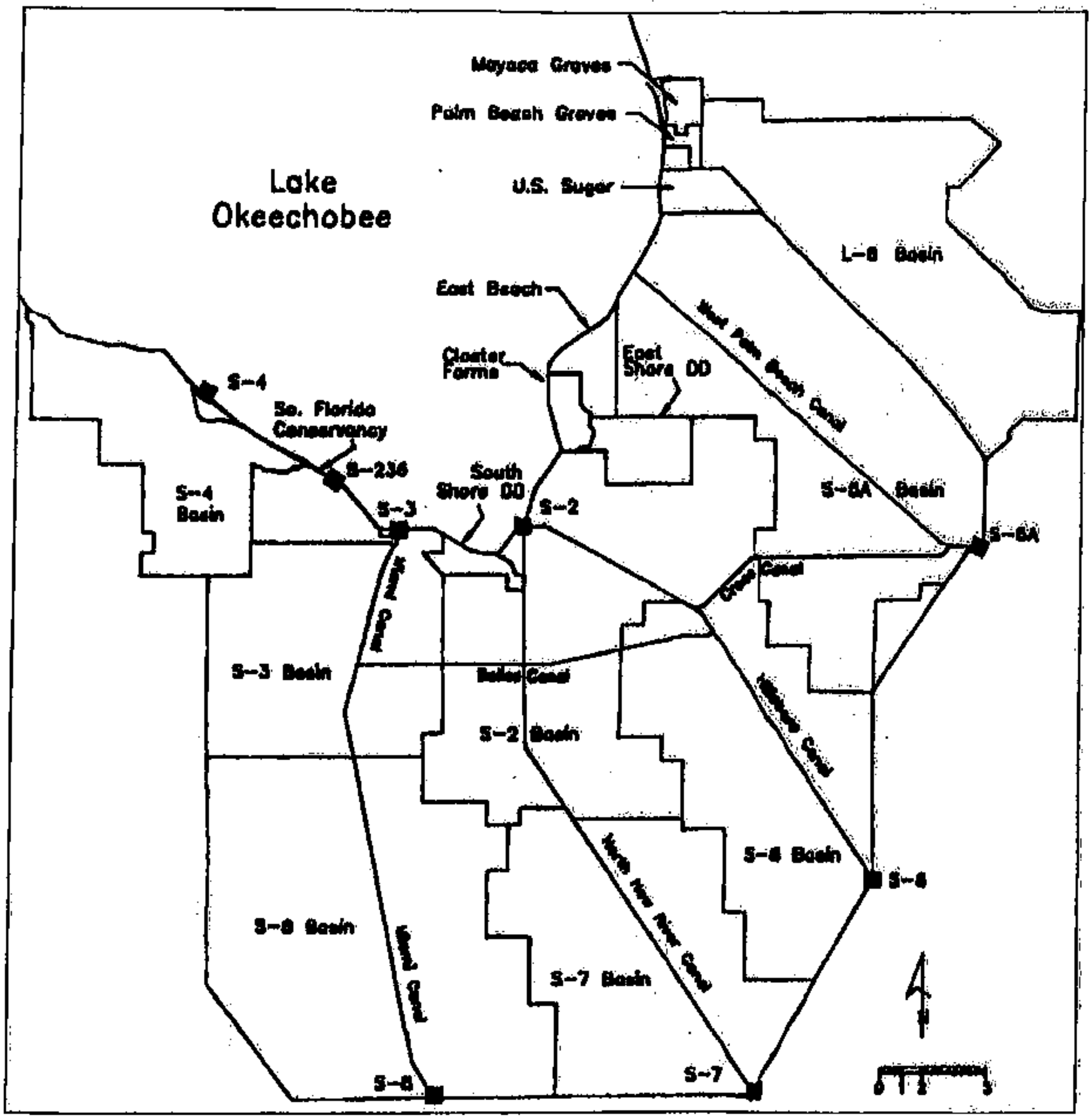
1. Description of the EAA and boundaries.

The historical Everglades area contains the largest known contiguous body of organic soils in the world (Jones, 1948; Stephens, 1974). The area known as the Everglades Agricultural Area (EAA), located south of Lake Okeechobee within eastern Hendry and western Palm Beach counties, encompasses an area of totaling approximately 718,400 acres (1,122 sq mi.) of highly productive agricultural land comprised of rich organic peat or muck soils (**Table 8**). A small portion of EAA mucklands are also found in western Martin county. Approximately 77 percent of the EAA (553,00 acres) is in agricultural production. The area is considered one of Florida's most important agricultural regions extending south from Lake Okeechobee to the northern levee of WCA-3A while its eastern boundary extends to the the L-8 Canal, while the L-1, L-2 and L-3 levees represent its westernmost limits (**Figure 14**). Nitrogen-rich organic (peat) soils and a warm subtropical climate permit the year round farming of sugar cane, winter vegetables and rice with a 1988 total economic impact estimated near $1.3 billion dollars (gross sales, Mulkey and Clouser, 1988).

The primary drainage and irrigation system consists of an extensive network of canals, levees, pumps and water control structures constructed by the USCOE as part of the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project) and is currently operated and maintained by the SFWMD. Drainage of the EAA is achieved through six primary canals (Hillsboro, North New River, Miami, West Palm Beach, Cross and Bolles canals) and an extensive network of secondary canals. Seven major pump stations (S-2, S-3, S-4, S-5A, S-6, S-7, and S-8) serve the EAA (**Figure 14**). Together these pumps have a design capacity to remove excess water from each basin at a maximum rate of 3/4 of an inch of runoff per day (Cooper, 1990). A total of nine smaller Chapter 298 drainage districts also operate pump facilities within the EAA (**Figure 14**). These districts, created after the Florida legislature passed the General Drainage Act in 1913, allow individual landowners join together to form secondary drainage districts with powers to issue bonds, levy taxes, and develop water management systems within the Everglades Drainage District boundaries (DeGrove, 1984; Izuno and Bottcher, 1987). In addition, individual farms operate numerous private pumps, some of which are portable, that move water to and from the main canals as part of the secondary system (Izuno and Bottcher, 1987).

Agriculture within the EAA requires extensive drainage of 553,00 acres of rich organic soil. Drainage of these muck soils for crop production causes soil oxidation and release of nutrients into EAA drainage waters and has been shown to be a major contributor of nitrogen and phosphorus loading to canal waters (Lutz, 1977a, 1977b; CH_2M-Hill, 1978, 1979). During the wet season, growers commonly pump large volumes of nutrient enriched water off their land to protect crops against flooding. These waters also are contaminated with high concentrations of chlorides, dissolved minerals, iron (derived from EAA groundwater), nutrients and trace levels of pesticides. With three major exceptions, almost all lands within the EAA are under cultivation. No retention areas or water storage facilities currently exist within the EAA to retain or treat farm water runoff.

Figure 14. Boundaries of the Everglades Agricultural Area (EAA) Portion of the Everglades SWIM Planning Area.



Prior to 1979, surface waters draining the northern one-third of the EAA were "backpumped" north into Lake Okeechobee through pump stations S-2, S-3 and S-4. The eastern and southern two-thirds of the EAA were drained by pump stations S-5A, S-6, S-7 and S-8 which pumped excess EAA water into the WCAs. Concerns over the ecological health of the lake resulted in the decision to divert the S-2 and S-3 basins waters southward to the WCAs under the Interim Action Plan (IAP) approved in 1979 and initiated in 1981 as part of the Temporary Operating Permit issued to the SFWMD by the DER (SFWMD 1989c, pg. 29). Under the IAP, EAA drainage waters can only be discharged into the lake under declared emergency conditions for water supply or flood control purposes. It is estimated that phosphorus loadings discharged to the WCAs through pump stations S-6, S-7 and S-8 have increased approximately

10 percent on an annual average basis since implementation of the IAP in 1979 (see Impacts of IAP on Water Quality section of this report).

EAA water quality and quantity issues appear to be intimately linked with two factors; the large volume of water that is pumped off EAA farmland to protect crops, and the release of nitrogen and phosphorus, derived from leaching and subsidence of EAA organic soils, into surface drainage waters.

2. History of the Development of Water Management in the EAA.

Florida gained statehood in 1848 at which time Buckingham Smith was appointed to assess south Florida's potential for development. Smith was the first to propose that the Everglades could be reclaimed for agriculture by digging canals and draining these vast wetlands. In 1850, the Federal government passed the Swamp and Overflowed Lands Act which gave the State approximately 20 million acres of land, including the 7,500 sq. mi. of wetlands known today as the Everglades Region (DeGrove, 1984).

In 1855, the Florida Legislature created the Internal Improvement Fund. The Fund's board of trustees was given the responsibility of managing lands given to Florida under the Federal Swamp and Overflowed Lands Act. Their charge was to sell and improve these swamp lands to generate revenues through drainage improvements (Jones *et al.*, 1948; Knecht, 1986). The Internal Improvement Fund emerged from the Civil War bankrupt. To solve this problem, the trustees contracted Hamilton Disston, a Philadelphia industrialist, to drain large areas of central and southern Florida in exchange for land deeded to Disston's company. This contract resulted in a series of canals being dug in the Kissimmee basin and construction of a canal between Lake Okeechobee and the Caloosahatchee River, providing an outlet to the Gulf of Mexico. Attempts were also made to dig a canal from Lake Okeechobee to the Shark River but failed as dredges encountered hard rock formations (Carter, 1974). In spite of claims by Disston's company that they had drained millions of acres of land, actually only about 80,000 acres were drained. These early efforts represent the first attempts to drain and manage water within the Everglades region as well as the genesis of today's billion dollar per year EAA farming industry (Izuno, 1987).

Full scale drainage and reclamation of the Everglades marked the administrations of Governor W.S. Jennings (1901-1905) and Governor Napoleon Bonaparte Broward (1905-1909). The Everglades Drainage District (EDD) was created in 1907 and empowered a 5 cent per acre tax to be levied on land drained within its boundary (DeGrove, 1984). The newly formed EDD completed a number of canals connected to tidewater which began major drainage of the region area opening it up to agricultural development. Although the EDD suffered financial collapse in 1928, the agency had constructed six major canals over 400 miles in length including the West Palm Beach, Hillsboro, North New River, and Miami canals (Knecht, 1986). As a result of these drainage improvements, agricultural development within the region flourished with the towns of Pahokee, Belle Glade, South Bay, Clewiston and Moore Haven becoming established along the south shore of Lake Okeechobee.

In the late 1920's, the need for better water control and flood protection became obvious to early EAA settlers. Construction of low muck levees along the south and southwest shore of Lake Okeechobee during the 1920's largely eliminated the lake's overflow south to the Everglades. The great hurricanes of 1926 and 1928 breached these levees causing the destruction of property and the loss of 2,100 lives (Gentry, 1984). This national catastrophe heightened interest at both Federal and State levels to provide more adequate flood protection for agriculture and urban interests south of Lake Okeechobee. The Lake Okeechobee Flood Control District was created in 1929. From 1930 to 1945, the federal government, through the USCOE, initiated flood control measures in response to regional flooding problems. Levees were constructed around the south shore of the Lake Okeechobee, and the St. Lucie and Caloosahatchee canals were enlarged. In the late 1940's, a new approach to water management in south Florida began. The drought of 1943-1944, followed by flooding in 1947, set the stage for development of a comprehensive water management plan that would address south Florida's flood and drought problems (Izuno, 1987).

Research conducted by the Florida Agricultural Experiment Station Experiment station in cooperation with the USGS, EDD and SCS demonstrated the need to replace the current inefficient water management system with a more complete system. In 1948, Bulletin 442, published by the Florida Agricultural Experiment Station, contained the results of almost a decade of extensive data collection by cooperating agencies (Jones, 1948). This publication represented the first attempt to develop a comprehensive water management system utilizing up-to-date geologic and soils data. In the past, construction of regional water management systems had taken place without the advantage of adequate scientific data. Bulletin 442, identified 700,000 acres of land in the upper Everglades as suitable for future agricultural development based on soil thickness and relatively impermeable geologic formations. Bulletin 442 also established the boundaries of the three Everglades WCAs based on areas of thinner peat soils and highly permeable geologic formations. The report discussed the need to develop the WCAs to serve multi-purpose water control benefits; prevention of muck fires and soil subsidence by raising water tables, protection of east coast well fields against salt water intrusion, and providing irrigation water for agriculture (DeGrove, 1984).

Probably the most significant legislative action concerning water management and the development of agriculture within the Everglades region was the passage of Flood Control Act of June 30, 1948 (Public Law 80-858), as recommended in House Document 643 (see Planning Document of this plan). In that year, USCOE (Jacksonville District), acting on request of state and local agencies, developed a comprehensive plan known today as the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF project) that would address all phases of the region's water management problems. The proposed goals and projects of the C&SF project were similar to those listed in Bulletin 442. The result of the legislation and the plan was that Lake Okeechobee was recognized as the major focus of South Florida's water management system -- the primary flood control and water storage facility for agriculture within the EAA, providing backup water supplies for east coast municipalities and other allied purposes. The plan also designated 800,000 acres of land south of Lake Okeechobee to be developed as agricultural, and 900,000 acres to be retained as WCAs, never to be drained or reclaimed (DeGrove, 1984). This ambitious plan called for construction of a levee parallel to the Atlantic coastal ridge and enclosure of the three WCAs by a system of levees to protect east coast urban areas from flooding by hurricanes, to recharge regional aquifers and protect against salt water intrusion. Agricultural development was of secondary importance (Carter, 1974). The plan was to expand and upgrade the water management system to include more than 1,400 miles of canals. levees and spillways (Light *et al.*, 1989)

In response to this federal action, the state Legislature in 1949 passed Chapter 378 F.S. creating the Central and Southern Florida Flood Control District (FCD) to act as the local sponsor of the massive C&SF Project. Subsequent legislation in 1972 expanded the agency's authority. The original plan called for the three WCAs to serve as flood control and water storage areas. During the FCD early years, the entire EAA and the three WCAs, encompassing over 1,500 sq. mi., were compartmentalized by canals and dikes. Water regulation schedules were designed to be lowest at the beginning of the wet season (June 1) in anticipation of major rainfall events and hurricane season. The schedules were formulated to have the highest water levels at the beginning of the winter dry season (Copper 1990, in press). Creation of the FCD is recognized as the beginning of the modern era of water management in the Everglades region (Izuno, 1987). The purpose of the 1949 agency was to provide flood protection, ensure adequate water supply, prevent salt water intrusion and enhance the environmental resources of the region including the newly created ENP. The FCD was subsequently renamed as the South Florida Water Management District (District) and given additional duties in 1972.

Actual construction of the WCAs began in 1953 with the construction of the eastern boundary of the Everglades WCAs (Klein, 1972) with WCA-1 and WCA-2 being enclosed by levees in 1960 and 1962, respectively. WCA-1 was designated as the Loxahatchee National Wildlife Refuge in 1951 under the Migratory Bird Act of 1929 (USFWS, 1972). In 1961, WCA-2 was divided by levee L-35B into WCA-2A and WCA-2B to prevent seepage losses to the system. WCA-3 was enclosed by levees in 1967 with the exception of a 7.1 mile strip along the border of the Big Cypress. WCA-3 was divided into WCA-3A and WCA-3B by levees L-67A in 1962 in an effort to reduce seepage losses from the system.

3. Recent Management Activities.

During the 1960s, a number of actions were taken at the national level in response to public concern over environmental protection and water quality. Federal legislation that was enacted included the Water Quality Act of 1965, the Clean Water Restoration Act of 1966, the National Environmental Policy Act of 1969 and the Federal Water Pollution Control Act of 1972. At the state level, the Florida Legislature in 1972 enacted the state Water Resources Act, the Environmental Land and Water Management Act and the Florida Comprehensive Planning Act.

In 1971, the Governor's Conference on Water Management in South Florida affirmed and emphasized the importance of conserving water and protecting its quality. In November 1972, the FCD held a hearing in West Palm Beach concerning "alleged environmental damage resulting from channelization of the Kissimmee River." Conclusions from this conference were that efforts should be initiated to: 1) correct pollution sources in the Kissimmee River; 2) plan and control all land and water use activities in the basin; and 3) restore Kissimmee River marshes.

Special Project. The "Special Project to Prevent the Eutrophication of Lake Okeechobee" was another product of the above referenced conference. This study was completed over a period of three years and concluded that Lake Okeechobee was in a eutrophic condition and that the resources of the lake needed to be protected as the basis of water supply for the south Florida region (MacGill *et al.*, 1976). Specific recommendations from this study included the following:

a) Water should be detained in upland areas as long as possible through storage in wetlands and the shallow aquifer.
b) Restoration and re-creation of wetlands should be encouraged.
c) Publicly owned lands should be reflooded.

d) Improved farming and ranching techniques should be applied throughout the basin as a means to improve quality of runoff to the lake.
e) Backpumping of nutrient-enriched waters from agricultural lands south of the lake should be terminated.
f) Methods should be investigated for the recycling of drainage waters from the EAA.

In response to the Special Project report, the Governor's Office in 1978, created the Kissimmee River Valley Coordinating Council (KRCC) as a means to encourage improved water management practices in that system.

Interim Action Plan (IAP). The DER and the SFWMD instituted the IAP in 1979 as a means of reducing backpumping of nutrient-enriched water into the lake from the EAA. Under this plan, pump stations S-2 and S-3 are no longer routinely operated to move water north into Lake Okeechobee, but only operate under emergency conditions for flood control or water supply purposes. Runoff from the EAA produced by normal rainfall is discharged to the WCAs. Based on the operational premises of the IAP, implementation of Level I Best Management Practices (BMPs) in the Taylor Creek/Nubbin Slough basins and establishment of nutrient loading criteria for the lake and its tributaries, the DER issued a Temporary Operating Permit (TOP) to the District in 1980 and a Lake Okeechobee Operating Permit (LOOP) in 1983 for the water control structures around Lake Okeechobee. It is estimated that phosphorus loadings discharged to the WCAs through pump stations S-6, S-7 and S-8 have increased approximately 10 percent on an annual average basis since implementation of the IAP in 1979 (see Impacts of IAP on Water Quality section of this report). Operation of the IAP has increased the amount of water that is discharged to the WCAs and decreased the amount of water entering the lake from the EAA.

Water Shortage Impacts. The SFWMD experienced two severe droughts in 1981 and 1985. In response to these events, a water supply management plan for Lake Okeechobee was developed that presented guidelines for water supply management of the lake during water shortage conditions. The District subsequently developed and adopted a Water Shortage Manual in 1986 that presented guidelines for the "Supply Side Management Strategy" for allocation of water from Lake Okeechobee to the EAA during periods of drought (SFWMD, 1987).

At the request of then-Gov. Bob Graham, DER Secretary Victoria Tschinkel created the Lake Okeechobee Technical Advisory Committee (LOTAC) in 1985 and charged this committee with the task of developing management strategies to control nutrient inputs into Lake Okeechobee. The state Legislature adopted the Surface Water Improvement and Management Act in 1987 and required the District to consider the recommendations developed by LOTAC, formed a new technical advisory committee (LOTAC II), and mandated development of a SWIM Plan for Lake Okeechobee. The Legislature mandated LOTAC II to study the impacts created by diversions of water away from Lake Okeechobee, including adverse impacts to the Everglades. Gov. Bob Martinez in 1988 extended the mandate of LOTAC II to continue studying Everglades and Lake Okeechobee issues through Spring, 1990.

Present Management. Today's drainage/irrigation system within the EAA is a complicated network of canals, levees, control structures and pumps. The original six major canals, (West Palm Beach, Hillsboro, Miami, North New River, Cross and Bolles canals) built in the 1920's still serve to drain the EAA although each canal underwent major improvements during the 1960's. Historically the EAA has depended upon the flood storage capacity of Lake Okeechobee to the north and the Everglades WCAs to the south as a means of removing excess drainage water from the EAA. Prior to adoption of the IAP in 1979, the northern one-third of the EAA was routinely backpumped directly into Lake Okeechobee through pump stations S-2, S-3 and S-4 located on the south shore of the lake, while the eastern and southern two-thirds of the EAA moved water south to the WCAs via pump stations S-5A, S-6, S-7 and S-8 Under the current Interim Action Plan, the S-2 and S-3 basins are now also routed south to the WCAs. Approximately 82 percent of the EAA land area (i.e. S-2, S-3, S-5A, S-6, S-7 and S-8 basins) now pump excess drainage waters into the three WCAs via pump stations S-5A, S-6, S-7 and S-8. Nine much smaller Chapter 298 Drainage Districts also currently discharge surface water runoff into Lake Okeechobee.

In the dry season, irrigation water is released from the lake into primary canals and is utilized by agricultural concerns as needed. The water is gravity fed through the primary canal network and then diverted or pumped into secondary canal systems for irrigation.

4. Land Use.

Land use and land cover types in the northern portion of the Everglades SWIM planning area were mapped by the South Florida Water Management District (SFWMD). These data are summarized in **Table 8.** This information was compiled during 1987 and 1988, and therefore may not be completely current.

Table 8. Generalized 1987/1988 Land Use/Land Cover Types and Acreages by Watershed for Major Sub-basins within the EAA.

Basin	Land Use Type							
	Agriculture, acres (% basin)	Urban, acres (% basin)	Rangeland, acres (% basin)	Forested, acres (% basin)	Wetlands, acres (% basin)	Water, acres (% basin)	Barren Land, acres (% basin)	Totals, acres (%)
S-2	101,242 (95.5)	4,053 (3.8)	43 (.04)	134 (.1)	--	505 (.5)	67 (.06)	106,044 (100.0)
S-3	64,071 (99.1)	260 (.4)	--	93 (.1)	--	161 (.2)	45 (.07)	64,630 (99.9)
S-4	36,807 (85.8)	3,660 (8.5)	283 (.7)	67 (.2)	1,465 (3.4)	251 (.6)	380 (.9)	42,913 (100.1)
S-5A	121,657 (97.8)	1,042 (.8)	34 (.03)	126 (.1)	4 (.003)	1,298 (1.0)	206 (.2)	124,367 (99.9)
S-6	80,583 (95.0)	941 (1.1)	179 (.2)	--	2,763 (3.3)	336 (.4)	1 (.001)	84,803 (100.0)
S-7	72,996 (78.3)	10,173 (10.9)	--	--	9,459 (11.2)	452 (.5)	144 (.2)	93,224 (100.0)
S-8	53,981 (47.5)	566 (.5)	18 (.02)	--	58,517 (51.5)	539 (.5)	--	113,621 (100
L-8	21,787 (24.5)	7,194 (8.1)	172 (.2)	1276 (1.4)	58,041 (65.4)	325 (.4)	--	88,795 (100)
TOTALS	553,124 (77.0)	27,889 (3.9)	729 (0.1)	1,696 (0.2)	130,249 (18.1)	3,867 (0.5)	843 (0.1)	718,397 (100)

Source: SFWMD Land Use/Land Cover Data Base, unpublished data.

In addition, the District has determined that although this data base may accurately represent the total amount of land in agricultural production (Level I), the amounts assigned to individual crop types (Levels II and III) do not accurately reflect the actual, current distribution of crop lands in the EAA. There are ninety Level III categories, which are grouped into seven Level I land uses: urban, agricultural, rangeland, forested uplands, wetlands, open water, and barren.

Agricultural areas occupy the majority of the northern portion of the study area (553,124 acres, or 77 percent). some areas of other crop land such as rice and citrus pasture, groves, nurseries, sod farms and confined feed lots. The major crops in the planning area include sugar cane, vegetables, and sod and smaller amounts of other crops such as rice, and citrus. In 1987, sugar cane production alone accounted for 405,000 acres of land use within the EAA (Coale, 1987). Dairy farms, improved and unimproved pastures, and horse training areas also comprise a significant land use in the study area. The S-5A basin is the largest basin in the study area, comprising about 124,000 acres of which, 97.8 percent, (or 122,000 acres), is in agricultural production primarily for sugar cane and vegetable crops. The S-8 basin is the second largest basin comprising about 114,000 acres, of which 47.5 percent (54,000 acres) is cultivated for sugarcane and sod production, while wetlands (Holey Land and Rotenberger tracts) account for 51 percent (58,000 acres) of the basin's land use.

Wetlands represent 18 percent (130,000 acres) of the EAA planning area, primarily in the S-8 and L-8 basins. Specific habitat types includes cypress and wet prairie, cypress alone, mixed, pine and wet prairie, melaleuca, cattails, sawgrass, and wet scrub and brush land. Most of the wetlands in the EAA are in public ownership and include the Holey Land, Rotenberger and Brown's Farm tracts. Open water (canals, lakes and ponds) represents about 0.55 percent, (3,867 acres), of the total EAA planning area.

Urban areas account for 19,000 acres, (2.7 percent), of the total land use in the study area and less than 10 percent of the land use in any individual basin. Urban uses can include residential, commercial, industrial, institutional, recreation, and transportation designations. The L-8 basin is the most highly urbanized of the basins in the study area (7,194 acres or 8.1 percent of the entire basin), although the S-4 Basin has a higher percentage of urban land use (3,660 acres or 8.5 percent). The other basin with significant acreage in urban is the S-2 Basin (4,053 acres).

Forested uplands include coniferous and non-coniferous vegetation and mixed forested areas. The non-coniferous designation includes nuisance species such as Australian pine (*Casuarina* sp.) and Brazilian pepper (*Schinus* sp.). Melaleuca is included in the above wetlands category. The study area contains 1,696 acres of forested lands, most of which (1,276 acres) are located in the L-8 Basin. Rangeland and barren land categories each account for about 0.1 percent of the total land use in the study area. Rangeland includes includes grassland, scrub, prairies, and brush land. Barren land includes mined areas, levees and spoil banks.

5. Geology.

Everglades organic soils (histosols) are underlain with a series of limestone rock formations of Pleistocene age. Directly beneath the organic muck soils is Lake Flirt marl, consisting of a soft, grayish-white calcareous mud containing bleached freshwater gastropod shells. Lake Flirt marl is of late Wisconsin and Recent age and is largely impermeable forming a tight water seal to groundwater percolation in many places. Underlying Lake Flirt marl is the Ft. Thompson rock formation consisting of alternating beds of marine, brackish and freshwater limestone, marl and shells. These materials were deposited in very low energy environments ranging from shallow inland seas to fresh-water marshes in response to changing sea levels conditions experienced during the Pleistocene Epoch. The permeability of both formations is low and almost totally prevents the infiltration of ground water into the underlying aquifer (Healy, 1975; Miller, 1988).

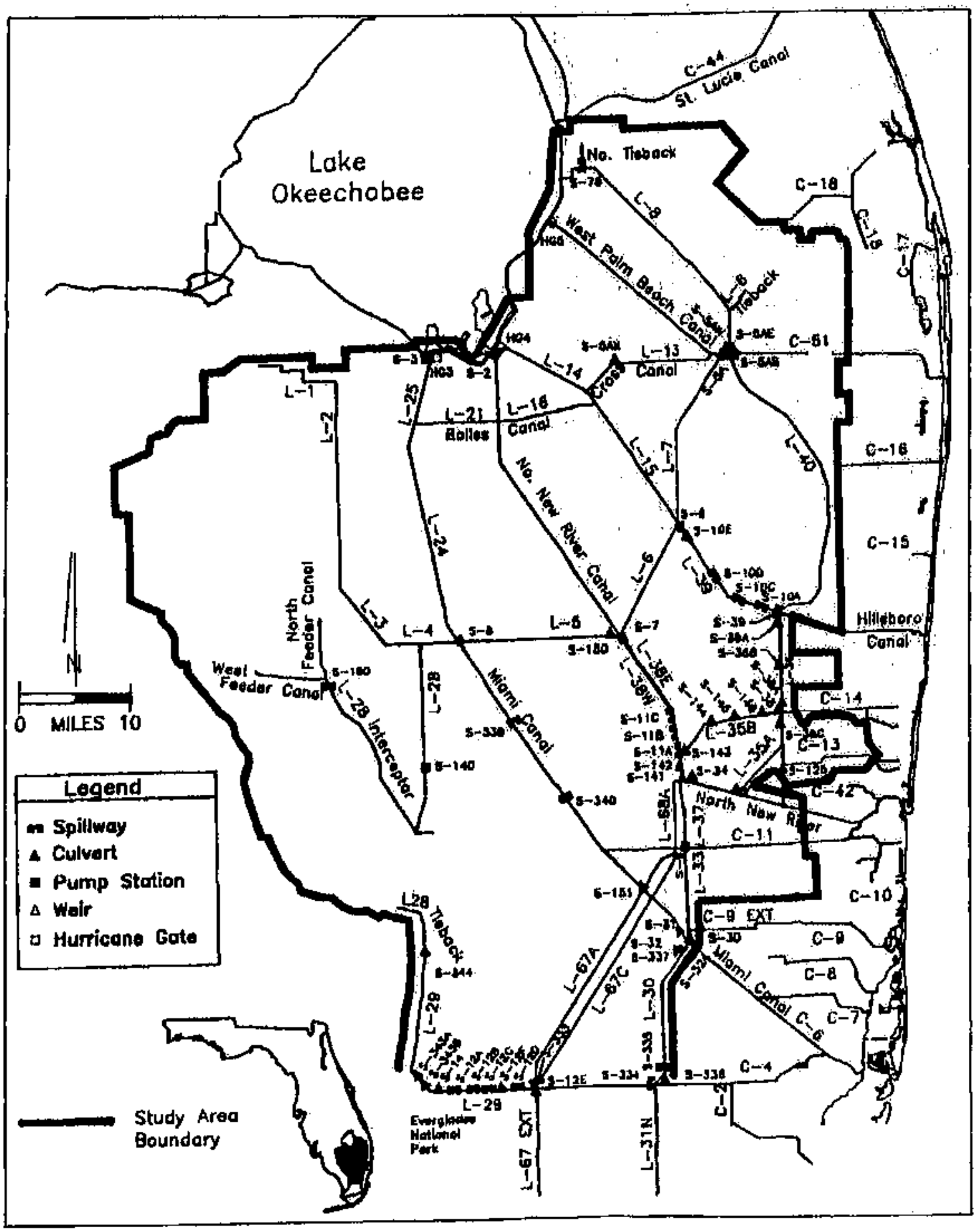
6. Hydrology and Water Management Features.

Prior to drainage of the EAA, the majority of the basin was a vast wetland area comprised of custard apple forests and sawgrass marshes located south of Lake Okeechobee. During flood stages, Lake Okeechobee overflowed its southern rim discharging large volumes of water across the upper Glades. Under these water logged conditions, peat and muck soils, up to 11 feet deep, formed within the basin over a period of 5,000 years.

The surface water management basins of the EAA were first delineated in the 1950's by the USCOE in their Part 1: Basic Report for the C&SF project. Based on the hydrology of these basins, the USCOE designed and constructed a complex system of canals, levees, and water control structures to provide flood protection for southern and central Florida (Cooper, 1989). Six major canals, the West Palm Beach, Hillsboro, Miami, North New River, Cross and Bolles canals represent the primary drainage canals for the EAA (**Figure 15**). These canals have four functions; (a) to provide flood protection and drainage, (b) to supply irrigation water to the EAA and for municipal water supply for the city of West Palm Beach, (c) to make regulatory releases from Lake Okeechobee, and (d) to transfer water from storage in Lake Okeechobee to storage in the Water Conservation Areas (Cooper, 1989). The EAA is comprised of seven water management basins named primarily after the major pump station which drains each basin. These basins include the S-2, S-3, S-5A, S-6, S-7 ,S-8 and L-8 basins (**Figure 14**). The S-4,and S-236 basins are not considered in this plan but are addressed within the Lake Okeechobee SWIM plan (SFWMD, 1989c). Detailed description of each basin are provided in Cooper (1989).

The design of the original project utilized Lake Okeechobee to the north as the principal flood storage area to handle excess water pumped off EAA farm lands. Prior to adoption of the Interim Action Plan (IAP) in 1979, the northern one-third of the EAA was routinely backpumped directly into Lake Okeechobee through pump stations S-2, S-3 and S-4 located on the south shore of the lake, while the eastern and southern two-thirds of the EAA moved water south to the WCAs via pump stations S-5A, S-6, S-7 and S-8 (**Figures 14 and 16**). Under the current Interim Action Plan, the S-2 and S-3 basins are now also routed south to the WCAs. Approximately 82% of the EAA land area (i.e. S-2, S-3, S-5A, S-6, S-7 and S-8 basins) now pump excess drainage waters into the three WCAs via pump stations S-5A, S-6, S-7 and S-8. As a result the EAA depends on the flood storage capacity of the Water Conservation Areas, and to a lesser extent, on Lake Okeechobee, as a means to remove water from the basin.

Figure 15. Major Water Management Features of the Everglades Agricultural Area and the Adjacent Water Conservation Areas.



Environmental Planning Division, SFWMD.

The growers remove runoff water from their lands by pumping to the six C&SF Project canals serving the EAA. Growers in general are allowed a maximum removal rate that is determined by a runoff formula and is almost always in excess of the basin wide design rate of three-quarters of an inch of runoff per day (Cooper, 1989). This amount was based on three considerations: (1) that not all land in the basin would be in agricultural production at one time, (2) that some of the land would be planted to water tolerant crops, and (3) that the canals in the basin have some storage capacity. Although the capacity of the canal system was not designed large enough to handle all the water discharged into from the EAA at one time, it was assumed that not all of the growers pump stations would be pumping or pumping to capacity at any given time (Cooper, 1989).

7. Soils.

Organic soils represent the dominant soil type found throughout the EAA. The accumulation of organic soils began in the upper Everglades about 4,400 years ago (McDowell et al. 1969). Organic soils, or histosols are formed primarily in shallow freshwater lakes or marshes which are inundated for much of the year. The growth, death and decay of marsh vegetation over thousands of years is responsible for the accumulation of thick deposits of organic muck or peat (histosols) up to 3.5 meters in depth south of Lake Okeechobee. The principal vegetation that accounts for histosol formation in the Everglades is a tall grass-like sedge, commonly referred to as sawgrass (*Cladium jamaicense*). Historically, peat accumulation in the Everglades proceeded at the rate of about 3.3 inches (8.4 cm) every 100 years. By 1914, organic soil accumulations in the Everglades reached their maximum average thickness of 134 inches (3.65 M). Two other plants, the Custard apple tree (*Annona glabra* L.), and elderberry (*Sambucus intermedia)* were two other marsh plants that also contributed to peat formation in the Everglades, principally near the southeast corner of Lake Okeechobee. (McDowell *et al.*, 1969).

Several soil classification systems have been devised for describing Everglades histosols (Baldwin and Hawker, 1915; Davis and Bennett, 1927; Jones, 1948). In 1975, the Soil Conservation Service (McCollum *et al.*, 1978) revised these earlier soil classification schemes and re-mapped the EAA as part of a soil survey for Palm Beach County. Seven basic soil types now are recognized in the EAA: Torry muck, Terra Ceia muck, Pahokee muck, Lauderhill muck, Dania muck, Okleelanta muck and Okeechobee muck. The Terra Ceia and Pahokee series represent about 80 percent of the soils reported in the EAA. Classification of these soils is largely based on soil properties and their depth to the limestone bedrock, with Terra Ceia and Okeechobee muck representing the deepest soils (>96 inches), followed by Pahokee muck (between 36-96 inches), Lauderhill muck (between 20 and 36 inches) and Dania muck as the shallowest (<20 inches). These five soil types probably represent the original sawgrass series identified in earlier classification schemes (Synder, 1987).

Soils in the Okeelanta series contain low-ash muck 16-40 inches deep over sand. Tory muck represents soils derived from custard apple forests once located on the southeast corner of Lake Okeechobee.

Underlying these organic deposits is the Ft. Thompson formation consisting of alternating deposits of limestone, sand, and marl. These limestone beds were deposited during the Pleistocene, when marine waters covered the peninsula. This limestone layer contains numerous solution holes due to chemical weathering of the limestone bed rock. In scattered areas, thin layers of impermeable, gray-colored marl exist between organic soils and the limestone caprock (Cox *et al.*, 1988).

Subsidence. Although histosols are considered highly fertile soils, they require intensive management for maximum crop yields. These soils were formed primarily under water logged, anaerobic conditions. Drainage and aeration cause shrinkage, consolidation and biological oxidation of these soils to a point where soil losses result in measurable changes ground level over time. This process is called soil subsidence. Studies have shown that subsidence caused by drainage of the EAA has reduced the thickness of these organic soils above the water table by about one half of their original depth (Stephens, 1969). Although a number of other factors contribute to soil subsidence, biological oxidation by fungi, aerobic bacteria and actinomycetes accounts for the majority of soil loss in the Everglades (Volk, 1973). The warm climate and,wet/ dry season cycles and high biological activity of soil organisms all contribute to the high rates of soil subsidence experienced in the EAA.

Soil subsidence rates have been carefully documented in the Everglades since 1920's with rates averaging near one inch per year in many locations (Snyder,1987;Cox et al. 1988). Re-wetting these soils by flooding or by maintaining a high water tables significantly reduces soil subsidence rates. The rate of subsidence appears to be directly correlated to the average depth at which the water table is maintained (Jones, 1948; Synder et. al. 1978). Fields maintained at a depth of 11 in. (30 cm), 23.6 in. (60 cm) and 35.4 in. (90 cm) experienced subsidence rates of 0.6 in. (1.6 cm), 1.4 in.(2.6 cm) and 2.2 in.(3.7 cm), respectively (Jones *et al.*, 1948; Snyder *et al.*, 1978). It is estimated that only 13 percent of the EAA will have soils thicker than 36 in. (91 cm) by the year 2000. Loss of these organic soils threatens the continuation of agriculture in the EAA in its present form (Snyder, 1987).

Soil subsidence is a major contributor of nitrogen and phosphorus into EAA drainage canals due to the high percentage of organic matter decomposition (95 %) associated with these soils (Morris, 1975). Studies conducted in the early 1970's estimated that EAA soil subsidence accounts for 24,480 metric tons phosphorus /yr (Morris, 1975). Although most of the nitrogen and phosphorus mineralized during oxidation remain in the soils (Fiskell and and Nicholson, 1985) some nutrients are discharged off-site to down stream water bodies where they become available as nutrients for plant growth.

Fertility. Although it could be argued today that the EAA contains some of the most fertile soils in Florida, this was not always the case. Early farming efforts found virgin Everglades soils low in phosphorus, potassium (Hammer, 1929), and the trace elements copper and manganese (Allison *et al.*, 1927). Early attempts to grow crops in muck soils were met with failure due to the lack of a number of trace elements. Allison *et al.* (1927) was first to recognize copper as the most important micronutrient required for maximum yields of most EAA crops. Three other trace elements; manganese, zinc and boron, were also identified as important micronutrients lacking in Everglades peat soils. Today, rice crops grown in the eastern EAA still experience seedling chlorosis due to the low iron content of its soils. Silicon is also reported to be low in most EAA soils for maximum yields of sugarcane. Today's high production rates are the result of intensive fertilizer management programs in force over many years by EAA growers (Sanchez, 1987).

Background levels of soil phosphorus (i.e. unfertilized muck soils) are reported to be highest in Terra Ceia muck due to either (a) the natural background levels of phosphorus available in the soil, or, (b) the greater ability of these soils to retain phosphorus after fertilization, or both (Wiggins and Bottcher, 1987). Pahokee muck represented the second highest background levels of phosphorus in EAA histosols.

Sanchez (1989) points out that EAA histosols vary considerably in their Fe, Al, $CaCO_3$ content, and other properties which influence the retention of phosphorus in EAA soils. Soils low in Fe, Al and/or $CaCO_3$ retain phosphorus poorly, while soils high in these constituents, leach relatively little phosphorus from the soil. Analysis of 20 different histosols indicated that the phosphorus buffering capacity of these soils varied by two orders of magnitude across the EAA (Sanchez and Porter, unpublished). Inorganic constituents appear to have a major influence on the uptake or release of phosphorus in organic soils. Information of how these soil properties affect phosphorus retention as well as information upon their distribution across the EAA is essential information required to form a basis for development of BMP alternatives for the EAA.

Farm Water Management Practices. The typical EAA farm is very large in comparison to coastal farming operations, encompassing many sections of land. Their large size is due in part, to the high cost of maintaining adequate drainage and irrigation systems which require both a surface water management permit and a consumptive use permit from the SFWMD and FDER (Izuno, 1987). The average farm water management system is a network of open ditches excavated to the limestone bedrock which are connected to a pump station located on one of the major canals operated by the SFWMD. The main ditch branches off at right angles into numerous lateral ditches approximately 6 ft. wide, spaced every 1/2 mile or so on the boundaries of a section or half section of the farm. Lateral ditches are generally 6 ft wide and branch off again at right angles to equally spaced field ditches about 3 ft. wide. These ditches are parallel and subdivide the farm into rectangular units approximately 660 ft. by 2,640 ft. These 40-acre blocks represent the basic water management unit for a typical EAA farm (Izuno, 1987) and are cited as the smallest, most economical unit for practical water control in the EAA (Casselman and Green, 1971).

Due to the flat terrain, most water drains through the soil profile before reaching the field ditches, although some surface water runoff is experienced during a major storm event. Irrigation/ drainage pumps generally are designed to remove 2 to 3 inches of rain off the fields in 24-hours to protect truck crops, while sugarcane requires 1 inch/24-hours (Stephens, 1955). Pump stations are designed for bi-directional flow to allow irrigation in the dry season, and for drainage and flood control during the wet season. These pumps are typically comprised of one or more low head, high capacity pumps capable of moving 20,000 gpm with lifts of up to 3-5 ft. (Jones, 1948). For irrigation, growers have historically drawn from water from these canals at rates of 0.25 in/ac per day up to 7.5 in/ac per month (Mireau, 1974). Portable pumps are also commonly used on many farms to flood fallow fields for insect control. Culverts, risers and boards are commonly placed at the inlets of each field ditch to control and distribute water more evenly.

Irrigation on most farms is achieved by pumping water from the main canal into the network of field ditches thereby raising the soil profile water table and providing water to the roots of a specific crop. Drainage of these fields is the reverse; pumps create an artificial hydraulic gradient which drains the ditches and lowers the soil water table. Sprinklers and crown flooding (planting on beds and flooding water between the beds) is also used for some specialty operations such as nurseries and germinations beds (Izuno, 1987). Some farmers increase their irrigation and drainage rates through the placement of a network of mole drains beneath the crop root zone.

Water Table Control Methods: The primary water management practice used by most growers is water table control. The storage of water within EAA organic soils can be substantial if implemented properly and can serve as a means of reducing the demand on regional water supplies for supplemental water use (Izuno, 1987).

Optimum water table levels recommended for sugarcane is between 18-24 inches below ground level, sod requires 12 inches, while vegetables require greater depths (about 2 feet). Maintaining optimum water table is recommended for reducing soil losses due to subsidence and sustaining maximum crop yields (discussion April 11 , 1989 with Steve Cox, SCS, West Palm Beach, FL.).

Water table control practices vary widely throughout the EAA. Other than "land forming", there are no widely accepted methods of water table management currently utilized by growers to to conserve water or reduce the volume of water discharged off their land. Desired water tables are maintained primarily by judging water levels on field ditch markers according to the grower's past experience (Izuno, 1987). If rain threatens, growers commonly pump these canals down to very low levels in anticipation of a major rainfall event. Often this procedure results in pumping larger volumes of water off the land than necessary resulting in a lower than optimum water table. Few growers utilize observational water table wells keyed to automatic pumping systems to determine the correct amount of irrigation or drainage required.

EAA Soil Water Chemistry. EAA muck soils represent an important reservoir of rich organic material that can be intensively managed. Morris (1975) estimated the total storage of phosphorus in EAA muck soils to be about 15 million tons of phosphorus and 210 million tons nitrogen. Of this total, approximately 88,600 tons of nitrogen (N) and 2,000 tons of phosphorus (P) are estimated to be found in unbound forms (Hortenstein and Forbes, 1972) and have the potential to be utilized by crops or exported from the EAA. These organic soils generally contain more than 2.5 percent nitrogen and 1.0 percent sulfur (Snyder, 1987). Background phosphorus levels in virgin (uncultivated) organic muck range from 0.02 to 0.04 percent phosphorus (Sanchez, 1987). Hammar (1929) reported the phosphorus content of Everglades soils to range from 0.08 to 0.35 percent. In virgin soils Nicholson (1983) found that inorganic phosphorus was only 24 percent of the total phosphorus content. By comparison, inorganic phosphorus in cultivated fields ranges from 50 to 72 percent of total phosphorus content.

In comparison to organic soils world wide, uncultivated Everglades histosols contain low concentrations of phosphorus, potassium, silicon and ash with a generally higher pH. Although the mineral content of muck soils along the south shore of Lake Okeechobee may range as high as 50 percent, the soils of the interior EAA have a much lower low ash content (10-20 percent), Hammar (1929) reported Organic soils within the extreme northern portion of the EAA were formed from extensive custard apple forests which once lined the south shore of the Lake Okeechobee. Today these soils are known today as "custard apple muck", or Torry muck (Hammar, 1929). Torry muck is much higher in ash content, silica, iron, aluminum and lower in calcium and nitrogen content than other EAA muck soils. Other muck soils; Terra Ceia, Pahokee, Lauderhill and Dania have low ash contents (Snyder, 1987). The moderately high pH exhibited by EAA muck soils in comparison to other organic soils is due to the contact with underlying limestone (calcium carbonate) bedrock which tends to buffer soil pH.

EAA muck soils vary spatially with respect to ash content content with highest values recorded in soils closest to Lake Okeechobee. Muck soil depths gradually decrease to the south and also near major canals as a result of localized soil subsidence. Localized variability due to variable bedrock is common.

Much of our understanding of EAA soil chemistry is derived from the nutrient requirements of crops grown within this agricultural region. The goal of most soil chemical assays were to determine the potential for maximum crop yield. The objective has been to identify limiting nutritional conditions and determine the appropriate soil amendment to correct deficiencies. Researchers at the Florida Agricultural Experiment Station at Belle Glade (IFAS) have found crop production to be limited by copper and manganese deficiencies. Many vegetable crops also have requirements for zinc and boron. Iron has been identified as a common deficiency in rice. Sugar cane and rice both show a positive response to the application of silicon soil amendments. Generally there is some advantage to applying small doses of nitrogen to many crops which provides an initial boost in soil fertility. Potassium has been found to be deficient for several crops and is routinely applied.

Although there is substantial storage of phosphorus within EAA muck soils, in many cases these levels are deficient for optimal growth of vegetable crops. Relatively little phosphorus is applied to sugar cane, based on soil test results (Sanchez 1989, in press). A common application rate for phosphorus deficient soils is 22 kg P ha^{-1}.. For vegetable crops, considerably more phosphorus is required with recommended rates ranging from 0 to 400 kg ha^{-1}. An average application for all crops types is 150 kg ha^{-1}. These high application rates are necessary because the unbound soil phosphorus is not sufficient to sustain maximum growth. There is an indication that soil phosphorus content increases with time under cultivation and that the surface water runoff from fields that have been cultivated for long periods of time contain considerably more phosphorus than newly cultivated muck soils (CH_2M-Hill, 1978) The mineral phosphorus fraction increases considerably more than the organic phosphorus fraction in response to fertilization and cultivation. These soils generally have high phosphorus retention capacities and can retain much of the phosphorus applied.

Although a complete understanding of the phosphorus sorption capacity of EAA organic soils is lacking, it appears that phosphorus sorption and retention is controlled by the amount of calcium, iron and aluminum complexes and precipitates present within EAA histosols (Sanchez, 1988; Richardson, 1985). Phosphorus retention is generally increased by the presence of iron and aluminum. Richardson, (1985) reports that among the 20 different types of organic soils, 87 percent of the variability of phosphorus sorption capacity is explained by extractable aluminum concentrations. Iron and aluminum content tends to increase with greater ash content (Sanchez, 1988) and may vary from less than 1 percent to greater than 5 percent. Phosphorus retention may also be increased by the precipitation of Ca-phosphates within organic soils that contain high amounts of marl or that are in close contact with the underlying limestone bedrock as is the case with many EAA soil types. Muck soils which contain a high calcium carbonate exhibit a higher phosphorus retention capacity (Sanchez, 1988). Lucas (1980) found that chemical liming of Okeechobee muck increased the phosphorus retention of these soils. Soil waters draining Pahokee muck were reported to lose less phosphorus than other EAA soils (Okeechobee muck) due to its higher iron and aluminum content. Measurements of phosphorus loss from some EAA soil profiles ranged from 4.7 to 9.2 kg P ha^{-1} (Forsee and Neller, 1942). However, estimates of off-site loss through surface drainage generally range from 0.2 to 3.5 kg P ha^{-1} (CH_2M Hill, 1978) indicating that some of the phosphorus lost from the soil profile is re-adsorbed. Lateral transport of soil water through the muck and porous limestone to drainage ditches has the effect of, reducing phosphorus concentrations. Hortenstein and Forbes (1972) concluded that the underlying marl was effective in removing phosphorus from percolating water. Only a small fraction of the phosphorus that is applied as fertilizer or is released from the soil by oxidation (subsidence) is transported to surface drainage ditches.

Effects of Soil Subsidence on Phosphorus Release. Approximately 7,000 kg ha^{-1} of organic carbon becomes mineralized annually within EAA soils (Tate, 1979; Volk, 1973). Terry (1980) reported that 7 g/m^2 of nitrogen is mineralized for each millimeter depth of muck lost due to microbial oxidation. Combining the amount of soil oxidized each year with the known soil phosphorus content, rough estimates of the potential mineralization of phosphorus from EAA soils range from 20 to 150 kg P ha^{-1} (Sanchez, 1988). Morris (1975) estimated that 24,480 metric tons of phosphorus is annually generated by subsidence within the EAA.

Phosphorus released during soil oxidation is most likely to be retained in the soil profile. Analysis of the phosphorus content of the muck soil profile indicates there is a substantial increase in phosphorus content at the surface but little increase in deeper layers (Fiskell and Nicholson, 1986). Most of the phosphorus released during oxidation is resorbed within the soil in a different form. This indicates that a majority of the fertilizer and oxidative-origin phosphorus is retained in the soil profile. Sanchez (1988) reported high phosphorus retention capacities for many EAA muck samples. Investigations of the fate of phosphorus in flooded organic soils (Lake Apopka) found that 47 percent of the mineralized phosphorus was retained in the soil (Reddy and Rao, 1983). Phosphorus released under aerobic conditions are more likely to be retained in aerobic than within anaerobic soils. Soils that have a high phosphorus retention capacity may effectively sorb (retain) phosphorus when drained, but release a pulse of phosphorus when initially flooded (Sanchez, 1988). A study of the flooding of organic soils adjacent to Lake Apopka were shown to increase the phosphorus release in drainage effluent 4 to 8 times (Reddy, 1983).

Crop Type and Fertilizer Use. The phosphorus dynamics of EAA soils is largely dependent on agricultural practices such as crop type, fertilization rates and timing, and water management practices. The options for varying water management and fertilization practices are determined to a large extent by crop and soil type and location. Sugar cane requires relatively little phosphorus while vegetables crops require high rates of fertilization. These recommendations are based on soil test data (Sanchez, 1989). As a result, the type of crop planted has the greatest impact on soil water phosphorus content due to the nutrient requirements of the species planted. Overall, vegetables crops cover approximately 10 percent of the EAA and are responsible for approximately one third of the phosphorus fertilizer applied (IFAS, 1989). Fertilization of sugar cane is considerably less and no phosphorus is applied in some areas. The efficiency of phosphorus use on vegetable crops could be improved substantially by the direct placement and timing of fertilizer applications. By applying a band of phosphorus directly below the root zone (i.e."band application") improvements in fertilizer use can be realized without affecting crop yields or product quality (Sanchez, unpublished data). Phosphorus application rates for vegetable crops could be reduced by as much as 40 percent by the band application technique as compared to conventional broadcast application methods, therefore reducing grower costs and the amount of phosphorus that might be discharged off-site (Sanchez, unpublished data). Soil testing still remains as one of the most viable strategies for growers to avoid excessive fertilization of their fields (Sanchez and Burdine, 1987).

Most of the phosphorus applied as fertilizer remains at shallow soil depths (Nicholson and Fiskell, 1985). Intensively tilled fields receiving years of fertilizer applications may accumulate sufficient phosphorus to exceed the phosphorus retention capacity at shallower depths allowing deeper penetration (Fiskell and Nicholson, 1986). It was speculated that fertilizer phosphorus was converted to an organic form and was not mobile under current land use. In soils used for vegetables and pasture there has been a considerable increase in soil phosphorus content.

The effect of different cropping practices is evident from an evaluation of phosphorus fate (Table 9). A comparison of sugar cane and vegetable crops indicates that five times more phosphorus is lost in drainage waters. Although a substantial mass of phosphorus was assimilated into the soil on site, high concentrations were detected in soil water and ground water.

Table 9. Fate of Phosphorus in EAA Soils and Soil Water for Sugar Cane and Vegetables (CH_2M-Hill, 1978)

Crop type	Amount of Phosphorus applied (1)	Phosphorus Uptake by Crop (1)	Phosphorus Assimilated in Soil Matrix	Phosphorus in Drainage waters (2)	Phosphorus in Soil Pore Water (2)	Phosphorus Concentrations in Groundwater (2)
Sugar Cane	20	7.3	9.7	0.71	0.29	0.09
Vegetables	106	8.2	85	3.58	7.51	1.03

(1) Kg phosphorus/ hectare (2) mg / liter Phosphorus

Effects of Water Management Practices on EAA Soils. Water management practices within the EAA have had a considerable influence on the retention and transport of phosphorus into area drainage canals. Drainage of the soil profile influences the release of phosphorus through oxidation and soil mineralization. Although high water tables greatly reduce soil subsidence and the loss of phosphorus from EAA soils, they also have the tendency to induce nitrogen and magnesium deficiencies in some crops (Shih and Rosen, 1985). Hortenstein and Forbes (1972) found that inorganic phosphorus concentrations were ten times greater in freshly drained muck compared to undrained muck. Phosphorus concentrations decreased with depth in the muck. Reflooding soils after extended drained periods may result in releases of phosphorus to surface waters. Soils that have a high phosphorus retention capacity may effectively retain phosphorus when drained but exhibit pulse releases of phosphorus when initially flooded. Water management of organic muck soils for irrigation or storm water drainage has the potential to enhance or diminish phosphorus release from EAA soils.

The degree to which irrigation and drainage are required, depend on the crop grown and the season. A number of crops (sugar cane, vegetables, sod corn and rice) are grown in different seasons and have different water requirements for optimum production. Each crop has a different tolerance to extent and duration of flooding without incurring significant economic loss. Water management for crop production may significantly effect the magnitude of phosphorus retention and transport.

The primary crop of the EAA is sugar cane which requires substantial irrigation during the summer growing season and drainage for high intensity storms that commonly occur during the summer and fall months. Mineralization of organic phosphorus may be reduced by maintaining higher water tables and reducing the rate of drainage. This practice requires greater water table control than is currently practiced within the EAA. One option to reduce off-site phosphorus loading during the summer months would be to pump drainage waters onto fallow fields. Since a common practice is to fallow and flood each field for pest management between replanting 1/10th to 1/4 of a given farm area may be fallow. Phosphorus in the discharge water may be hydraulically loaded on the fallow field resulting in increased percolation through underlying limestone and increased phosphorus retention.

Production of winter vegetables is an important activity during the winter growing season. These crops are very sensitive to water table manipulation. A high water tables reduces rooting depth and sensitizes the crop to flood damage. Low water tables result in drought stress. Most vegetables are very intolerant of even brief flooding periods and require immediate drainage. Sugar cane is also impacted by flooding during the winter months and requires immediate drainage.

8. Water Quality in EAA Canals.

A more comprehensive discussion of inflow water volumes, flow-weighted nutrient concentrations, and nutrient loadings at pump stations S-5A, S-6, S-7 and S-8, is presented in section B.5 "WCA Water Quality Characteristics: Sources of Phosphorus."

The quality of canal water draining the EAA was evaluated using the period of record 1979-1988 under pumping and "no flow" conditions. Data from pump stations S-5A, S-6, S-7, and S-8 were examined statistically for seven water quality parameters including turbidity, chloride, color, total nitrogen, nitrate, nitrite and total phosphorus concentrations (**Table 10**). These data were subdivided into two groups, (1) parameters measured when the pump station was in operation and (2) water quality parameters measured when the pumps were not in operation, i.e. "no flow" conditions. Results of these analyze indicate several trends as shown in **Table 10;**

Table 10. Statistical characteristics of selected physical and chemical water quality parameters obtained from discrete water samples collected from EAA pump stations. Sample means obtained represent periods of time when pumps where in operation versus "no flow" conditions. Period of record, 1979- 1988.

Parameter	S-5A	S-6	S-7	S-8
Turbidity (ntu)	10.2 (4.5)*	4.2 (3.7)	4.4 (3.4)	15.2 (5.0)*
Chloride (mg/L)	204 (197)	192 (182)	159 (143)*	89 (81)
Color (p.u.)	173 (159)	145 (139)	127 (106)*	126 (109)*
Total N (mg/L)	6.66 (4.95)*	4.59 (4.38)*	4.06 (3.38)*	3.85 (3.00)*
NO_3 (mg/L)	2.806 (1.063)*	1.241 (0.791)*	1.255 (0.772)*	1.071 (0.700)*
NO_2 (mg/L)	0.040 (0.119)*	0.067 (0.089)*	0.017 (0.044)*	0.029 (0.035)
Total P (mg/L)	0.177 (0.185)	0.091 (0.104)	0.075 (0.085)	0.138 (0.100)

Numbers without parentheses refer to parameters measured when pump station was in operation; values in parentheses ( ) represent parameters measured when pumps were not in operation, i.e. "no flow" conditions; * asterisk = statistically significant difference between sample means; Source: SFWMD, unpublished data.

(a) Water at all four EAA pump stations contain high concentrations of total nitrogen, nitrate, nitrite, Total phosphorus and chloride as well as high color and turbidity values. These results are similar to previous analysis of water quality data collected from the primary water conveyance canals of the EAA (Lutz, 1977; CH_2M-Hill, 1978).

(b) Highest concentrations of total phosphorus, total and inorganic forms of nitrogen as well as chlorides were observed at pump station S-5A located within the eastern portion of the EAA. Nitrogen concentrations were significantly higher at all stations during pumping events.

(c) Sampling station mean concentrations for the majority of parameters sampled were higher in the eastern portion of the EAA (S-5A, S-7 and S-7) with generally lower station means observed to the west (S-8).

9. Flood Control.

The EAA depends upon the pump stations at its north and south boundaries for flood control. The original design for the pump stations provided an approximate equal distribution of pumping flood waters to the north as to the south. The south flood control pumping is into the WCA and the northern pumping is into Lake Okeechobee. Stations S-5A, S-6, S-7 and S-8 pump from the EAA into the WCAs.

As discussed earlier, concerns over the accelerated rate of eutrophication in Lake Okeechobee led to a decision to change the relative distribution of flood or drainage water pumped from the EAA north to Lake Okeechobee on an average annual basis. This redistribution was called the Interim Action Plan (IAP). Under this plan, 95% of all flood waters and water released from Lake Okeechobee for water supply purposes are pumped from the EAA into the Water Conservation Areas. Only an estimated 5% is pumped north to Lake Okeechobee during flood or drought emergency conditions. The IAP did not alter operation of the S-5A pump station.

The flood protection level of service for the EAA is currently as designed in the original project documents. The infrequent use of the northern pump stations is an indicator of the design level, but also is an indicator of the need to retain the pumping capacity for flood control purposes.

10. Economics.

The Everglades Agricultural Area (EAA) comprises about 700,000 acres. The area is dependent on the WCAs for flood control, especially since the implementation of the IAP to protect Lake Okeechobee. The WCAs also provide some of the water supply to the EAA by means of backpumping and other special operation of structures. The primary source of supplemental irrigation water for the EAA, however, is Lake Okeechobee, which also provides emergency flood protection for northern portions of the EAA.

The EAA economy is based largely on agriculture. The population is concentrated in the following towns located around the rim of the Lake with 1987 permanent populations as follows; Clewiston 5,828, South Bay 3,666, Belle Glade 17,184, and Pahokee 6,633. Besides being the hometowns of most of the permanent labor force, they support much of the agriculturally related supply and processing activities and are the headquarters of many of the agricultural enterprises. They also support the industry oriented to serving recreational use in the southern part of Lake Okeechobee. A seasonal influx of agricultural workers increases the population of towns in this area during the winter sugarcane harvest and vegetable seasons. For instance, the City of Belle Glade estimates that its population increases by about 6,000 during this period. In recent years several thousand offshore workers, largely from the West Indies, have been utilized by agricultural employers in the EAA. These workers are housed in special labor camps provided by their employers.

Agriculture in the EAA relies on the 526,000 acres of rich muck soils now irrigated, drained and under cultivation. On these acres are produced sugarcane, vegetables, sod and rice. The estimated acreage and sales value of these crops, as provided by IFAS and the Palm Beach County Extension agent, are provided in **Table 11.** Due to the different sources and the different time periods that were observed, the land use data in this table differ slightly from the SFWMD data base as shown in **Table 9.**

Table 11. Acreage and Values of Agricultural Production in the Everglades Agricultural Area

Crop	Acreage (X1000)	Farm Sales ($MILLIONS)
SUGAR CANE	433	$350
VEGETABLES	23	110
SOD	29	30
RICE	3	3
LIVESTOCK	32	9
OTHER	6	7
TOTAL	**526**	**$509**

Data Sources: Sale value per acre from IFAS, Palm Beach County Extension; estimated acreages from SFWMD; sugar cane value from Mulkey and Clouser, 1988

Farm employment in the EAA is very seasonal because of the seasonal nature of the sugarcane harvest and the seasonal nature of vegetable production. Year round farm employment is about 4,100 full time employees. This rises to about 17,600 individuals during the peak season which includes about 10,441 foreign workers (FSCL, 1988). In 1988, the employment payroll was over $226 million for the sugarcane industry. Farm processing and supply employment are not included in these figures and are discussed below.

While the vegetables are packed and shipped fresh and are not subject to extensive processing, sugar cane is locally processed which adds considerably to its value and the output of the industry. Six sugar mills in the EAA process all the cane produced in south Florida, both inside and outside the EAA. All sugar cane is grown under contract for processing at one of these mills. Location (proximity) is a major factor in determining the mill which will be contractually linked to each cane field. The mills produce raw sugar, molasses and other by-products, the total value of which is about $577 million or an increment of $225 million over the value of the cane on the farm. A portion of the raw sugar receives further processing at the sugar refineries located in the EAA. This adds to the value of the industry output but statistics on these establishments are not published because of disclosure limitations. A large portion of the raw sugar is processed outside of Florida.

11. Recreation, Navigation and Public Access.

Recreational Activities. As mentioned above, the EAA is also the base for the recreational use of the southern portion of Lake Okeechobee. Additionally, outdoor recreation activity within the EAA is concentrated in the primary drainage canal system and on four state-owned tracts of land - Lake Harbor Waterfowl Management

Area and Rotenberger, Holey Land and Brown's Farm Wildlife Management Areas. Management of wildlife resources and public use in these four areas is the responsibility of the Florida Game and Fresh Water Fish Commission (FGFWFC).

Deer and wild hog hunting are the principal activities conducted within the three wildlife management areas, and access is generally off of project levees. Walk-in hunting is allowed; however, hunters utilize a variety of specialized off-road vehicles (ORVs) to travel within these areas because of the difficult terrain and the fact that they are seasonally inundated. The amount of water present often influences the mode of transportation selected and can have an impact on harvest rates. Access to the waterfowl management area is by foot only. Bank fishing is the principal activity conducted in the EAA canal system. There has been little demand for boating access to these canals in the past, and as a result there are few improved access sites. Many fishermen generally do not view these canals as prime fish producers because of the absence of adjacent marsh systems and concerns over runoff and pumped discharges from adjacent agricultural fields.

Holey Land Wildlife Management Area. The Holey Land Wildlife Management Area is a 35,026 acre tract lying in the S-8 and S-7 sub-basins. It is wholly state owned and managed by the Florida Game and Freshwater Fish Commission (FGFWFC). The area is heavily used for white-tailed deer and also hog hunting. A small amount of waterfowl hunting occurs, and wintering water birds such as white ibis, great egrets, and snowy egrets can be spotted between September and February. The 3,000 acres of shrub habitat is most important for the deer who also forage among tree island, sawgrass and mixed sawgrass/shrub vegetation. A 1983 survey indicated a population of 600-700 deer on the tract, up from an estimated 200-300 deer population in 1982. At present, the deer population appears to be declining due to a peat fire which destroyed substantial habitat and forced deer onto adjoining tracts. FGFWFC estimates that the Holey Land tract sustained 3,517 man-days of use in the July 1, 1988, to June 30, 1989 year. Most hunters walk-in off canal levees, but controlled use of airboats and specially equipped outdoor recreational vehicles is common in order to access the interior.

In 1983, a Memorandum of Understanding (MOA) was entered into by the DER, the Board of Trustees of the Internal Improvement Trust Fund, the FGFWFC, and the District (SFWMD, 1983). The Agreement establishes a process for the implementation of a plan to restore Everglades values associated with the Holey Land/Rotenberger Tract and provides for the establishment of water regulation schedules which 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 that will provide hydroperiod improvements for both the Holey Land and WCA-3A.

Rotenberger Wildlife Management Area. Rotenberger Wildlife Management Area consists of 23,970 acres of state-owned and leased private land (roughly 40% of total acreage) managed by the FGFWFC for deer and hog hunting. It is located within the S-8 sub-basin and is separated from the Holey Land by the Miami Canal. A 1983 FGFWFC survey of this tract found that most deer occur in the northern half of the acreage. Like the Holey Land, hunters walk-in off perimeter canal levees although airboats and special outdoor recreation vehicles are also in limited and controlled use. Seasonal inundation and a year-round high water table deter internal access. Between July 1, 1988, and June 30, 1989, FGFWFC estimates that this area sustained 1,246 man-days of hunting use. Due to impeded external access and no improved parking, most of this use is assumed to originate locally.

Brown's Farm Wildlife Management Area. Brown's Farm Wildlife Management Area is a 4,460-acre, state-owned tract managed by the FGFWFC and commonly used for white-tailed deer and hog hunting. Hunter access to the tract is off canal levees on an walk-in basis. The difficult terrain and seasonal inundation make the interior generally reachable only by special outdoor recreational vehicles. Between July 1, 1988, and June 30, 1989, GFC estimates that Rotenberger received 2, 864 man-days of deer hunting use.

Lake Harbor Waterfowl Management Area. The Lake Harbor Wildlife Management Area is located on the Miami Canal, south of Lake Okeechobee and north of Holey Land and Rotenberger. The area is publicly owned by the state and leased to the FGFWFC which allows a private lease to cultivate rice for both harvest and wildlife habitat. No recreational vehicles are allowed.

Other EAA Water-Related Recreation. An existing component of the corridor-designated but uncertified Florida National Scenic Trail skirts the eastern perimeter of Lake Okeechobee and follows a southwesterly direction through the EAA. With other segments still under development, the trail will be available for public use on national park land and national forest land segments. Most privately-owned segments of the trail will be open only to the Florida Trail Association, an established public interest organization which has been instrumental in trail designation and development. Water-enhanced and water-dependent recreational uses include hiking, bird watching, and nature observation.

B. WATER CONSERVATION AREAS (WCAs).

1. Descriptions of WCA Boundaries and Hydrologic Features.

Water Conservation Area 1 (WCA-1). Water Conservation Area 1, also known as the Arthur R. Marshall Loxahatchee National Wildlife Refuge, includes 227 mi^2 (145,280 acres) (588 km^2) of Everglades wetland habitat. WCA-1 lies west of U.S. 441 and south of State Road 80 in Palm Beach County, Florida, 15 miles from the Atlantic Ocean. The LNWR boundaries are generally defined by the outer boundary of the levee right-of-ways surrounding WCA-1. However, there are several places where the current refuge boundary does not quite close and at least one other place, around S-39 where the LNWR extends beyond the surrounding levee right-of-ways.

The essential water management features of the WCA system and the adjacent Everglades Agricultural Area (EAA) are shown in **Figure 15**. The western boundaries of WCA-1 border the EAA. The EAA includes large sugar cane, winter vegetable and sod farm operations. The area east of WCA-1 includes a number of rapidly expanding urban communities, although several sections immediately adjacent to WCA-1 are undeveloped and contain extensive wetlands. To the south and southwest of the refuge lie WCA-2A and WCA-3A.

Historic Conditions and Present Management. Water Conservation Area 1 represents one of the last remnants of northern Everglades habitat. WCA-1 is part of the historic Everglades system that once stretched from the south shore of Lake Okeechobee 90 miles south to the mangrove estuaries of Florida Bay (**Figure 2 and Figure 5**). Prior to the construction of water management canals and levees, WCA-1 was hydrologically interconnected with WCA-2 and WCA-3 as part of one vast overland sheet flow system. The water regime for WCA-1 consisted of both rainfall and overland sheet flow. Pre-drainage sheet flow patterns within WCA-1 were primarily from north to south in the northern end of the refuge, curving to a northeast to southwest direction in the south end as reflected in the orientation of present day tree island communities as shown in remote sensing mapping data supplied by the USFWS (Richardson, J. as cited in LOTAC-II, 1988). Its interior is characterized by a labyrinth of small tree islands set in a matrix of wet prairies, sawgrass ridges and aquatic slough communities comprising about 98 percent of the refuge (USFWS, 1972). The western and southwestern portions of the refuge open up to a large open expanses of sawgrass prairie, interspersed with wet prairie, sloughs and tree island communities more typical of other portions of the Everglades. The refuge also contains a 400-acre cypress swamp.

WCA-1 is part of a huge freshwater storage area connected by a series of canals and levees built by the U. S. Army Corps of Engineers (USCOE). In 1949 this area was placed under the jurisdiction of what is now the South Florida Water Management District (District or SFWMD). An agreement between the District and the U.S. Fish and Wildlife Service (USFWS) enabled the establishment of the national wildlife refuge in 1951 under the authority of the Migratory Bird Conservation Act of 1929. Current management objectives of the refuge are:

1. To provide optimum habitat and wildlife protection for endangered and threatened species of wildlife which are native to the Everglades.
2. To provide wintering habitat for migratory water fowl.
3. To provide habitat for a natural diversity of wildlife species.
4. To provide opportunities for environmental education, interpretation and wildlife-oriented activities.

Creation of the Refuge. On June 8, 1951 the Loxahatchee National Wildlife Refuge was established under the basic authority of the Migratory Bird Conservation Act of 1929 (USFWS, 1972). Creation of the refuge was included in the congressional authorization of the Central and Southern Florida (C&SF) Project that was constructed by the USCOE. The USFWS leases 143,085 acres of WCA-1, from the state of Florida through a Cooperative License Agreement with the District. The lease expires in 2001 and is automatically renewable for three 15-year periods. The USFWS owns in fee title 2,550 acres which were purchased with federal Duck Stamp funds and are divided into five units or compartments. Compartments A, B, C, and the cypress swamp are located on the east side of the WCA-1 near the refuge headquarters office, which is located west of Boynton Beach. Compartment D is located outside the refuge's western levee, just north of the intersection between L-7 and L-39 levees.

On November 6, 1986, the refuge was renamed the Arthur R. Marshall Loxahatchee National Wildlife Refuge under Public Law 99-614 to recognize the accomplishments of the late Arthur R. Marshall Jr., who throughout his life crusaded to preserve and protect south Florida's natural resources. Currently, the refuge attracts almost 500,000 visitors a year for wildlife observation, environmental education, sport fishing, water fowl hunting and other wildlife-oriented activities (LOTAC-II, 1988).

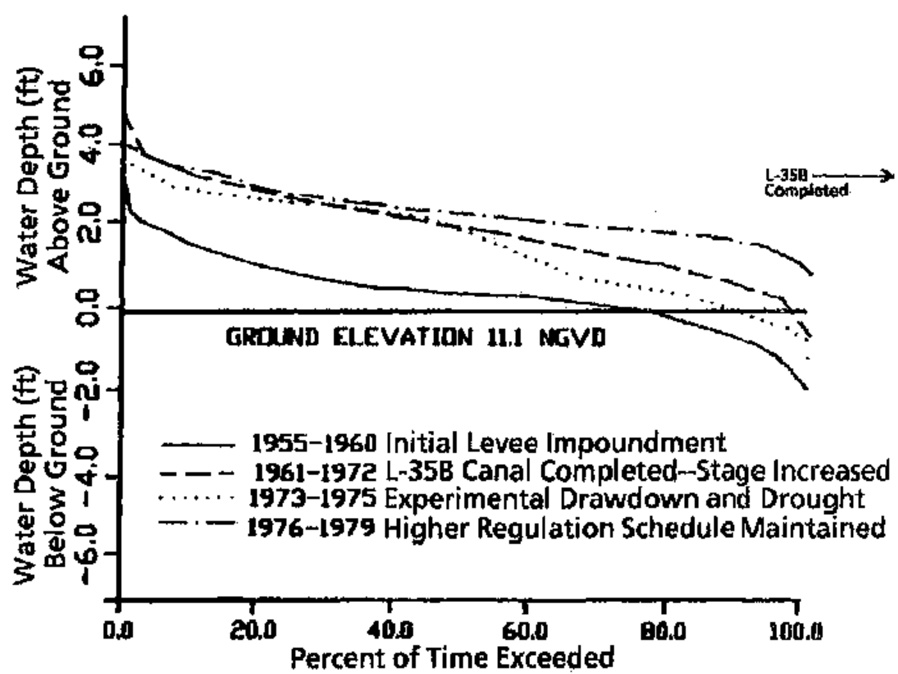
Hydrology and Water Control Features. Today, WCA-1 is encircled by 56 miles of levees and canals. Water levels are controlled by a network of pump stations, levees and water control structures. WCA-1 is the only conservation area completely encircled by canals. The water management facilities hydrologically are connected with Lake Okeechobee, the Everglades Agricultural Area (EAA), WCA-2, WCA-3 and the Atlantic Ocean. Rainfall represents the major source of water inflow into WCA-1, accounting for about 54 percent of the refuge's water budget. Pump station S-5A, located at the northern tip of the refuge near 20-Mile Bend, moves water into the refuge from the West Palm Beach Canal accounting for approximately 30 percent of the inflow water. Pump station S-6, located on the refuge's western border, pumps water from the Hillsboro Canal into the southwest portion of the refuge accounting for about 15 percent of WCA-1 inflow water. Approximately 45 percent of the WCA-1 water inflow originates as drainage from agricultural land located north and west of WCA-1 (see "WCA Water and Nutrient Budget" section of this report).

Two small pumps operated by the Acme Improvement District are located in the L-40 levee on the northeastern boundary of the refuge. These pumps drain primarily residential/urban lands (Wellington) and can move water in and out of the refuge. Acme represents only a minor fraction (<1 percent) of the refuge's water budget.

Four water control structures (S-10A, S-10C, S-10D and S-10E) exist along WCA-1's on the southern levee of L-39 (Hillsboro Canal). The S-10 structures allow water to flow southward out of the Hillsboro Canal and WCA-1 into WCA-2A if so desired. The U.S. Army Corps of Engineers retains ownership and supervises the daily operation of the S-10, S-11 and S-12 structures which control water movement into and out of the WCAs. The District operates these structures under contract with the Corps and simply carries out the Corps' orders with respect to their operation. The Hillsboro Canal (L-39), located in the extreme southeast corner of the refuge, drains WCA-1 to the east through S-39 which provides water supply to urban areas and discharges drainage waters to tide water. To the north, the S-5A structure can be used to move water north out of the refuge into the L-8 canal. There are four other small privately operated structures in the L-40 levees; one of these is operated by the USFWS. These structures constitute less than 1percent of the refuge's annual water budget

Water Conservation Area 2 (WCA-2). This sawgrass wetland encompasses an area of 210 sq. miles (547 km^2) and represents the smallest of the three Everglades Water Conservation Areas. Water Conservation Area 2 is situated directly south of WCA-1 and directly west of the rapidly growing community of Coral Springs. It is located in southern Palm Beach and northern Broward counties (**Figure 2**). The area is bordered on the west by U.S. 27 and WCA-3A, and on the south by Interstate 75. WCA-2 was created as a critical component of the C&SF Project in the early 1960s. This project was designed to provide flood protection, water supply and environmental benefits for the region. Water levels in this area are controlled by a system of levees and water control structures which encircle the WCA-2A marsh. Levee construction in the early 1960s cut off historical overland sheet flow to the system. Impoundment of these waters, coupled with regional water management practices, significantly altered the marsh's natural hydroperiod by increasing water depths for long periods of time causing loss of tree islands and wet prairie communities (Dineen, 1972). 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. The effects of this construction on the area's hydrology are shown graphically as percent exceedance curves, as shown in **Figure 16** (from Worth, 1988).

Figure 16. Historic Stage Level Percent as Exceedance Curves for WCA-2A from 1955-1979.



Year	# Days Dry
1955	110
1956	256
1957	100
1958	0
1959	0
1961	15
1962	0
1963	70
1964	0
1965	0
1966	0
1967	0
1968	0
1969	0
1970	0
1971	47
1972	0
1973	71
1974	13
1975	12
1976	0
1977	0
1978	0
1979	0

Source: Worth, 1988

Hydrology and Water Management Features. Creation of WCA-2A was also part of a massive regional flood control and water supply (C&SF) project built by the USCOE. Management of water levels within WCA-2A is primarily the responsibility of the District in accordance with regulation schedules set by the USCOE. Responsibility for wildlife management within WCA-2A and WCA-2B is delegated to the Florida Game and Fresh Water Fish Commission (FGFWFC) under lease from the District. WCA-2A provides a variety of multipurpose functions including;

1. Aquifer recharge for east coast well fields,
2. Protection against salt water intrusion,
3. Flood protection for agricultural and east coast urban areas,
4. Preservation of Everglades wildlife including threatened or endangered species,
5. Provide for recreational opportunities (hunting, fishing, boating and wildlife observation) for south Florida residents.

Approximately 58 percent of the inflow water entering WCA-2A originates from the Everglades Agricultural Area (see WCA Nutrient Budget section of this report). 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 (CH_2M-Hill, 1978; Lutz, 1977a, 1977b). Nutrient enriched canal water enters the marsh from the north via four water control structures (S-10A, S-10C, S-10D and S-10E) located on the L-39 levee (Hillsboro Canal), which drain WCA-1 and the EAA, and from the west via pump station S-7. Over the past 10 years (1978-1988), WCA-2A has received approximately 88 metric tons of phosphorus and 3,070 metric tons of nitrogen on an average annual basis as the result of inflows from these five water control structures (see WCA Nutrient Budget section of this report). The absence of an interior perimeter canal along the marsh's northern levee allows nutrient enriched canal water to sheet flow across the marsh. When surface water stages exceed the regulation schedule, water is discharged from the area principally through the three S-11 structures (S-11A, S-11B and S-11C) located along the southwestern levee of WCA-2A. Other minor discharges occur through the C-13 and C-14 basins by way of S-38 (gated culvert) to the southeast, and the S-144, S-145 and S-146 structures which discharge to WCA-2B to the south (Cooper, 1990, in press).

Water Conservation Area 3 (WCA-3). Water Conservation Area 3, the largest of the three Everglades WCAs, lies to the west and southwest of WCA-2A and is located in western Broward and Dade counties. Its boundaries are the L-5 levee, the Rotenberger and Holey Land wildlife management areas, and the EAA to the north; the L-29 levee, Tamiami Trail (U.S. 41) and Everglades National Park to the south; the boundaries to the east are levees L-30, L-33, L-37 and L-38; boundaries to the west are levee L-28, the Big Cypress National Preserve, and the Miccosukee and Seminole Indian reservations.

WCA-3 is over twice the size of WCA-1 and WCA-2 combined and covers an area of 915 sq. mi. (2,370 km^2). 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 expands south to Tamiami Trail. WCA-3A is the only water conservation area that is not entirely enclosed by levees. A 7.1-mile stretch has been left open on the mid-western side of WCA 3A. This opening, the L-28 Gap, allows overland flows to enter WCA-3A from the Big Cypress National Preserve and other western basins (Leach *et al.*, 1972). WCA-3 is bisected by several interior canal systems. Major inflows include drainage from the EAA from the north includes the Miami Canal,and a combination of agricultural and WCA-2A sheet flow from the northeast (L-67A Canal). In 1962, WCA-3 was divided into WCA-3A and WCA-3B (786 and 128 sq. miles, respectively) by construction of two interior levees (L-67A and L-67C) so that water losses due to levee seepage could be reduced.

Hydrology and Water Management Features. Management of water levels within WCA-3A and WCA-3B is primarily the responsibility of the District in accordance with regulation schedules set by the USCOE. Responsibility for wildlife management within WCA-3A and WCA-3B is delegated to the FGFWFC under lease from the SFWMD. WCA-3A provides a variety of multipurpose functions including the following:

1. Aquifer recharge for east coast well fields,
2. Protection against salt water intrusion,
3. Flood protection for agricultural and east coast urban areas,
4. Preservation of Everglades wildlife including threatened or endangered species,
5. Provide for recreational opportunities (hunting, fishing, boating and wildlife observation) for south Florida residents.and,
6. Provide a source of high quality surface inflow water for Everglades National Park.

Rainfall is the major contributor of water to WCA-3A, accounting for over 59 percent (1.85 million acre feet) of its measured annual average inflows from 1978-1988 (see Part II, section B.5, "Sources of Phosphorus"). Primary surface water inflows include the following: (a) the S-11A, S-11B, and S-11C (S-11 structures) account for about 17 percent of all inflows to WCA-3A. These three water control structures transfer water from WCA-2A and the L-38E canal under U.S. 27 into the northeast section of WCA-3A; (b) pump station S-8 (10 percent of all inflows) which drains a 178 sq. mi. portion of the EAA (S-3 and S-8 basins) served by the Miami Canal; (c) pump station S-9 (4 percent) which drains urban lands located in in the western C-11 basin in western Broward County; (d) the L-3 canal (2 percent) which drains the northwest portion of the EAA and transfers this water to WCA-3A; (e) pump station S-140 (3 percent) located on the western L-28 borrow canal which drains a 110 sq. mi. drainage area served by the L-28 borrow and the L-28 interceptor canals; (f) the S-150 structure (2 percent) located on the L-5 borrow canal which gravity drains a portion of the EAA (the S-7 basin); (g) the L-28 Interceptor Canal (2 percent) which drains lands west of WCA-3A (i.e. Feeder Canal basin); (h) the L-28 gap which receives drainage waters from the Big Cypress National Preserve and the L-28 Tieback levee borrow canal; and (i) from the North New River Canal by way of G-123 and S-142 (Cooper,1990, in press; see also Part II, section B.5 "Sources of Phosphorus").

When water levels exceed their regulation schedule, water can be discharged to Everglades National Park principally through S-12A, S-12B, S-12C and S-333 to the Tamiami Canal via the S-343 structures; to WCA-3B by way of S-151; and to Big Cypress National Preserve through the S-344 structure. When WCA-3A is being managed for water supply, discharges can be sent to ENP, southeast Dade County, South Dade Conveyance System, WCA-3B, and Big Cypress National Preserve.

In pre-drainage times, WCA-3A probably received most of its water from local rainfall and by overland surface flow from the Everglades to the north and the Big Cypress Basin to the west. By 1945, drainage and land reclamation activities south of Lake Okeechobee had significantly lowered surface water and groundwater levels within the northern Everglades. Water control structures had been placed in all major canals discharging to the Atlantic Ocean to prevent saltwater intrusion and over-drainage during the dry season. In 1953, a levee was completed along the eastern side of the Everglades. Flows to tidewater via major canals were reduced and much of the historic flow was diverted to the south, with the majority of flow occurring along the eastern section of the Tamiami Canal (Leach *et al.*, 1972). In 1962 the USCOE completed the L-29 levee further enclosing WCA-3A, and in 1967, the USCOE completed the L-67 Extension Canal. These projects had significant impacts on the hydrology of WCA-3A as well as the quantity, distribution and timing of flows to Everglades National Park. These impacts included:

1. Most surface waters discharged from WCA-3A now pass through the S-12 structures in to ENP. Surface water flows to Shark River Slough (ENP) became largely a function of upstream water management policy and does not reflect historical flow patterns.

2. The L-67 extension levees isolated the northeast portion of Shark River Slough from the main slough system, reducing the free flow of water between these areas.

3. Surface water flow from WCA-3B to Northeast Shark River Slough was almost eliminated. Seepage under L-29 and the Tamiami Trail was about 15% of the 1953-1961 period of record, while flows in the western sections doubled those recorded from 1953-1961 (Leach *et al.*, 1972).

4. Excavation of the L-67 Extension Canal resulted in too much water being discharged into the central portion of Shark River Slough during wet periods. These disruptions in the natural hydrologic conditions, caused by L-29 and the L-67 extension, coincided with declines in wading bird populations within ENP (Kushlan *et al.*, 1975).

Although the C&SF Project was now able to deliver more water to the Park, the WCAs tended to retain inflows during the 1960s for water supply purposes rather than pass it downstream to ENP. These reduced flows, coupled with several droughts during the 1960s, led to passage of federal legislation (Public Law 91-282; the River Basins and Monetary Act) in 1970 guaranteeing minimum deliveries of 315,000 acre-feet annually to ENP on a monthly schedule. Deliveries were set at approximately the median of historic monthly flows (Kushlan, 1987). At this time, the park agreed to take any extra water available above the minimum schedule, allowing regional water managers to discharge excess water as they deemed appropriate (Kushlan, 1987). Discharges to ENP increased dramatically after this period, frequently raising high water stages and duration of inundation to levels above the historic norm. In 1984, Section 1302 of Public Law 98-181 changed the 1970 legislation, allowing deliveries to ENP to deviate from the minimum flows set earlier. A rainfall-driven model was developed in 1985 for WCA-3A that based the delivery of water to ENP on natural upstream rainfall patterns (MacVicar, 1985; Neidrauer and Cooper, 1989). This plan appears to be effective and has been extended, through federal legislation of the Water Resources Development Act of 1988, until January 1992.

A number of earlier construction projects have also had major impacts on the hydrology of WCA-3A. Construction of the L-29 levee across the southern end of WCA-3 in 1962 interrupted the southerly flow of water to ENP, causing the ponding of water in the southern portion of WCA-3A. Improvements to the conveyance capacities of three canals (the Miami, L-67C and L-38W canals) were completed between the years 1962-1968. These physical alterations were designed to move more water south to ENP during low flow conditions. These canal improvements greatly increased the flow of water south, creating impounded water conditions at the southern end of WCA-3A, while over-draining the north end of the marsh and causing an increase in the frequency of peat fires. Both of these conditions are considered harmful to Everglades plant communities and wildlife habitat (Zaffke, 1983). In 1980, two environmental enhancement structures (S-339 and S-340) were constructed north and south of Alligator Alley (State Road 84). These structures were designed to force water out of the Miami Canal and to flow across over-drained areas of the northern WCA-3A marsh in an attempt to improve overland sheet flow, maintain higher groundwater level elevations and slow water movement to the southern end of WCA-3A (Zaffke, 1983).

Construction projects along Alligator Alley have also had impacts on the hydrology of WCA-3A. Although culverts were installed to allow passage of water through the highway, the borrow canal on the north side does not distribute flows evenly, causing enhanced flow to pass through seven of the ten culverts. This has resulted in the drying of areas on the south side of the highway during periodic low flows. Current reconstruction of the roadway (to create I-75) includes plans to reduce problems caused by earlier designs.

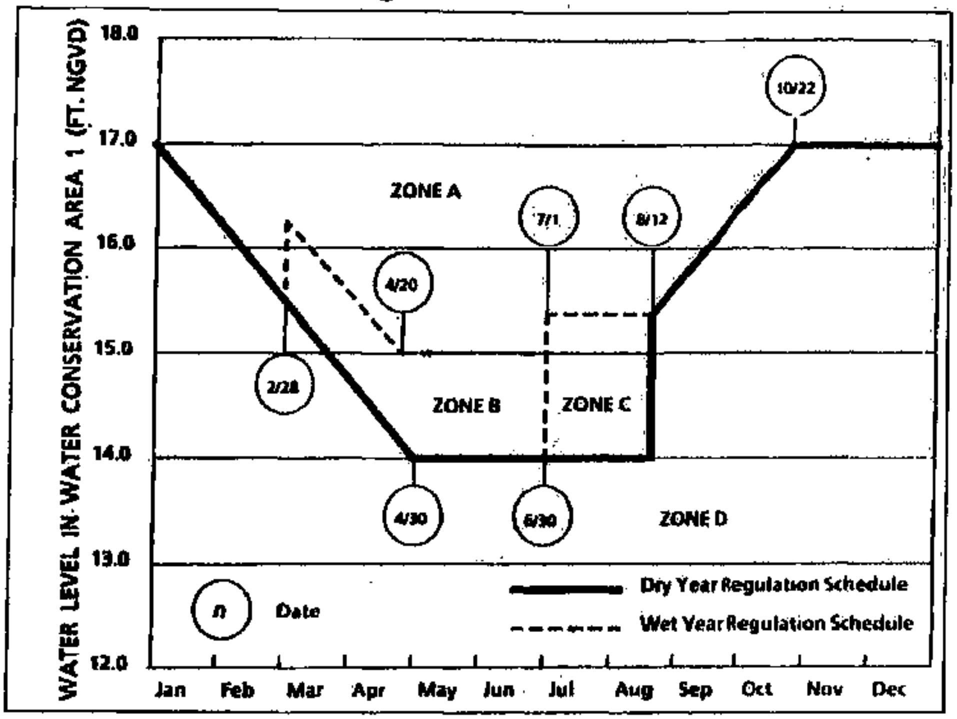
2. Regulation Schedules.

Water levels in the WCAs are controlled on the basis of water regulation schedules. These schedules establish minimum and maximum water levels (stages) for the WCAs throughout the year. These schedules provide the basis for determining whether water should be allowed to flow in or out of the WCAs through the water control structures. Water regulation schedules for each WCA were developed through interagency cooperation. The authority to change regulation schedules and water control plans for the CSF Project rests with the Secretary of the Army and authority to approve changes has been delegated to the USCOE Division Engineer (South Atlantic Division). Regulation schedules and operating criteria are revised and refined as needed. Agencies or jurisdictions interested in modifying the existing regulations may request changes to the schedule. The request, depending upon its intent, goes through an individual and coordinated review process with the USCOE and SFWMD. Schedule changes undergo internal review and a series of public hearings, before final approval. The SFWMD is responsible for allocating water supply releases from the WCAs. The USCOE is responsible for the operations and activities mandated by federal legislation or federally controlled jurisdictions. The USCOE has final authority over water supply and flood control regulation schedules, and over establishing minimum permissible water levels in matters affecting navigation.

WCA-1. Figure 17 presents the regulation schedule for WCA-1. This schedule has four distinct zones (A-D) designated for specific water management actions within a given time of year. When water levels fall within Zone D, the area is regulated for water supply purposes. Zones B and C were implemented as part of a schedule developed in 1975 designed to allow periodic drying of WCA-1. An extended drying of the marsh for at least 30 days occurring roughly once every three years, is desired. The schedule may range from 14 - 17 ft. NGVD to 15-17 feet. NGVD depending on climatic conditions.

The schedule for WCA-1 has been altered twice since the original 1960 federally approved plan was implemented and the U.S. Fish and Wildlife Service has developed a proposed modification of the current schedule for consideration in 1989-

Figure 17. Regulation Schedule for WCA-1.



Source: Cooper, 1990, in press.

90. The original schedule called for water levels to fluctuate from 14 to 17 feet (NGVD), but allowed the water to drop very quickly, leaving the area's marsh dry for extended periods of time. During the first nine years of operation of this schedule, water levels frequently fell to 11 feet NGVD. In 1969, WCA-1's schedule was altered, raising the minimum to 15 feet NGVD to augment water supply in the dry season. This new schedule kept much of the marsh inundated throughout the year, eliminating seasonal drying of the marsh.

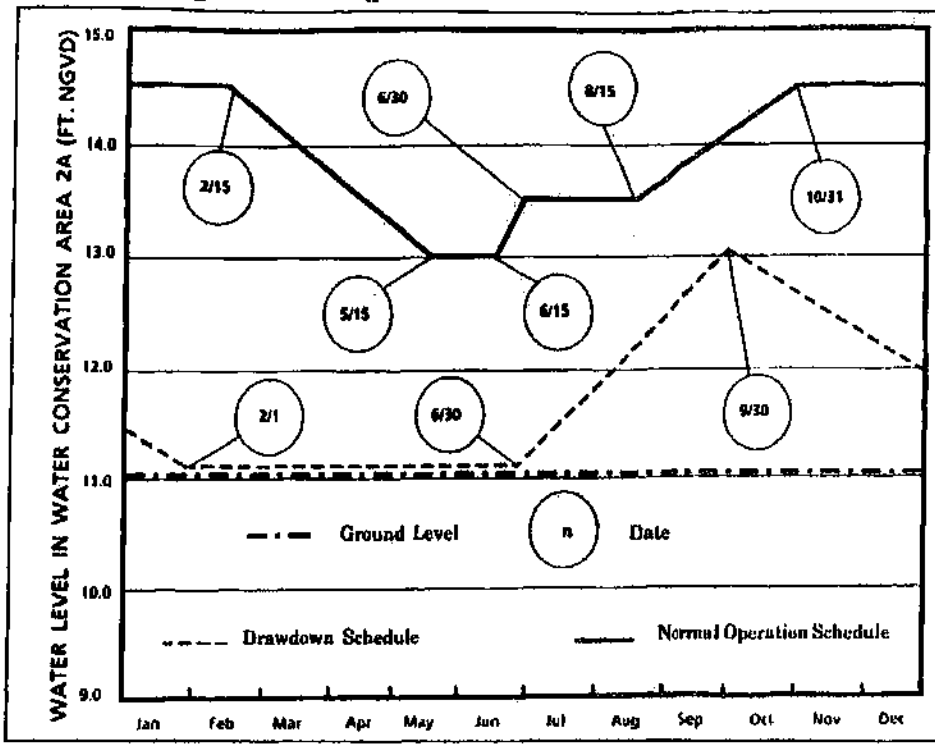
The USFWS proposed that the schedule be changed three years later and by 1975 obtained the District's support and USCOE approval for a modification of the original 14 to 17 foot schedule. The 1975 schedule, which is still in effect, is designed to allow the marsh to dry out for a period of 30 days or more every two or three years, on average. If the alternate schedule zone line is crossed at any time after February 28, the alternate schedule is followed for the remainder of the year.

The newest proposal by the USFWS represents an attempt to build even more flexibility into the area's water schedule. The USFWS is expected to ask the District and USCOE to initiate schedule modification proceedings in 1990.

WCA-2. The schedule for WCA-2A was originally set too high to support Everglades habitat and has been the subject of extensive research and experimentation by the District. The original 1961 schedule called for water levels to fluctuate from 12 to 14.5 feet. The schedule was revised even higher in 1970 to a range of 13 to 14.5 feet with only a 30-day period at the lower end (Figure 18).

Observed changes in the ecology of WCA-2A caused District scientists in the early 1970s to initiate efforts to lower the water schedule and provide for annual drying of the interior marsh. Extended high water killed significant stands of trees,

Figure 18. Regulation Schedule for WCA-2A.



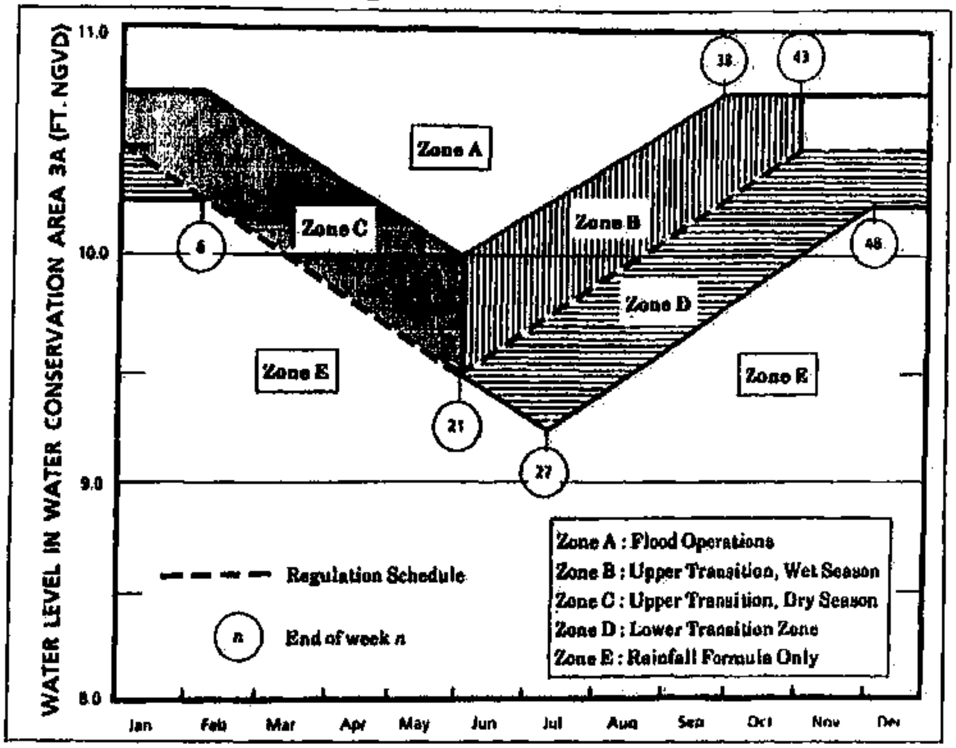
Source: SFWMD (Cooper, 1990, in press)

eroded islands, and caused other undesirable vegetation changes in the area (Dineen, 1972, 1974; Worth, 1988). In 1980, the schedule was revised at the District's request to an interim plan of 9.5 to 12.5 feet, an extreme drawdown that was in place for eight years. Extensive research by the District during this time led to an interim schedule of 11 to 13 feet, which the District proposed be adopted as the official schedule for the area. In 1989, USCOE approved the District's schedule proposal.

WCA-3. The regulation schedule for WCA-3A is perhaps the most complicated and difficult schedule to describe or implement. The schedule ranges from 9.5 to 10.5 feet, but includes a series of five zones to modify discharges to ENP when water levels are above or below the optimum target (**Figure 19**). The size of WCA-3A, and the number of inflow and discharge points preclude intensive management of water levels in the area. Discharges at the southern end of the area flow directly into ENP and were modified three times in the past decade to alleviate problems resulting from too little discharge in the early years, and heavy flood discharges during the dry season which impacted nesting wading birds and other wildlife during the 1970s and early 1980s.

The original schedule was set shortly after ENP and the District's predecessor agency were created. In 1970, Congress adopted an ENP-backed plan to establish a minimum monthly volume of water to be delivered to the park. This resulted in significant flood damages from dry-season flood waters, which were discharged from area 3A when the water schedule was exceeded. In 1985, the district developed and was granted permission to experiment with water releases based on rainfall and evaporation over the Everglades. The Rainfall Plan distributes water over a broader area than the original operating schedule whenever possible.

Figure 19. Regulation Schedule for WCA-3A.



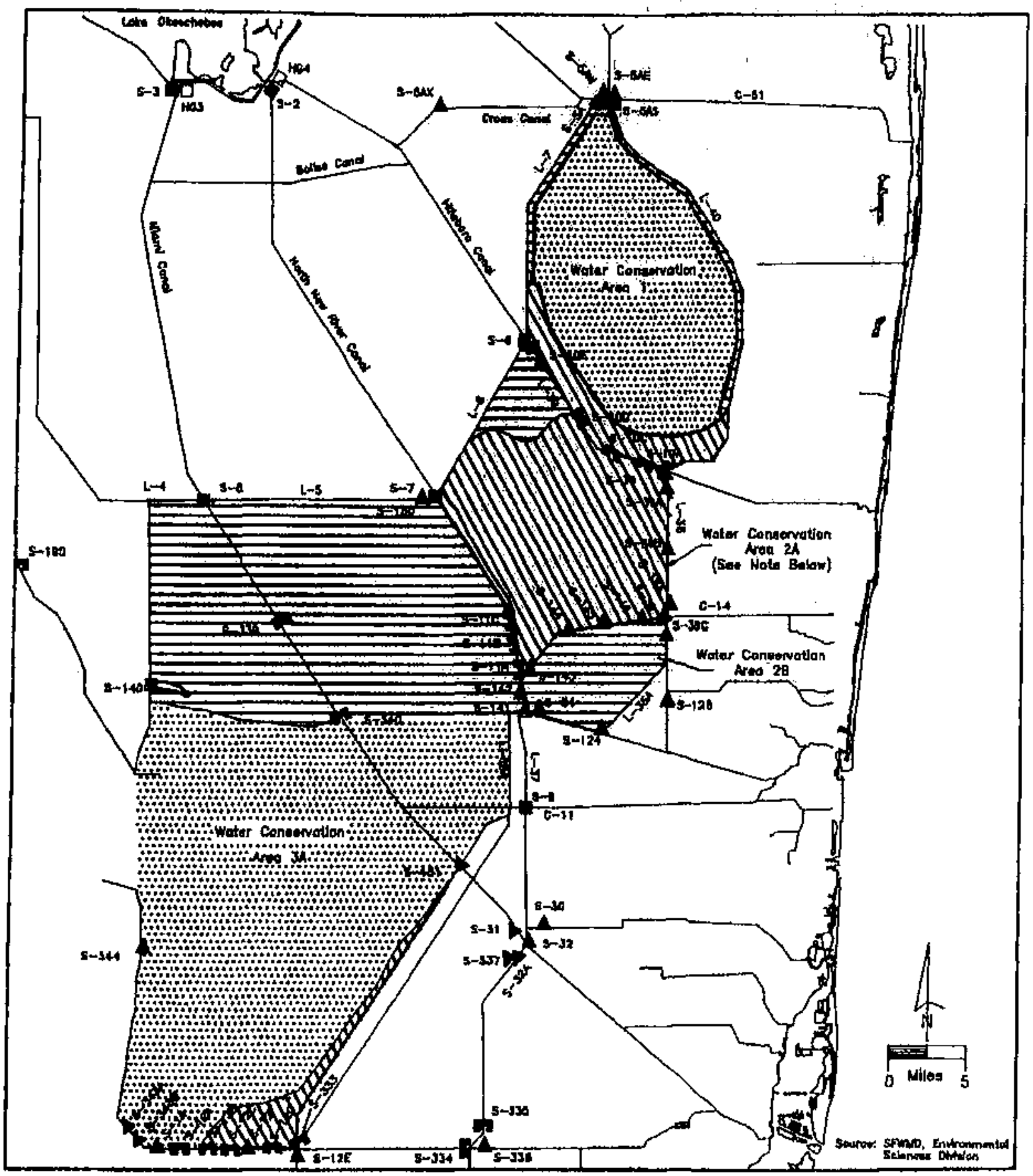
Source:SFWMD (Cooper, 1990)

Other problems within WCA-3A, primarily overdrainage in the northern end, are not due to the schedule but instead are caused by the design of water-control facilities. These regulation schedules are open to review and change if the agencies involved find better ways of regulating the water levels. Methods have been established by the USCOE and the District for review and modification of these schedules.

3. Vegetation Characteristics.

Many areas of the WCAs have been affected by construction and operation of the C&SF Project. The Project has caused some areas of the northern Everglades to become overdrained, while others areas of the marsh have been subjected to deep water or stabilized water level conditions. These hydrological modifications of the original overland sheetflow system have played a major role in determining the present day vegetation characteristics of the area (Loveless *et al.*, 1970; Dineen, 1972; McPherson, 1973; Alexander and Crook, 1984). Figure 20 presents a generalized map prepared by SFWMD biologists in an effort to identify areas of the WCA marsh where vegetation communities are presumed to have been most affected by hydrological change including overdrainage (shortened hydroperiod), prolonged periods of inundation (extended hydroperiod), as well as areas of the WCAs which exhibit hydroperiod characteristics which support Everglades plant communities similar to those originally described by Davis (1943a). The following discussion below attempts to identify the vegetation characteristics of each WCA as well as point out those areas of the marsh which have been most affected by hydroperiod changes.

Figure 20. Generalized Map of the WCAs indicating Areas of the Marsh Presumed by the SFWMD to be Affected by Overdrainage or Prolonged Hydroperiods.



Overdrained Areas which have experienced invasion by terrestrial species

Areas of the marsh having a more typical hydrologic regime supporting historic Everglades vegetation

Areas of Extended Hydroperiod

Note: From 1972–1979 WCA–2A was used as a regional water storage area and was not allowed to dry out on a seasonal basis. An extended drawdown of WCA–2A was conducted from 1980–1984 in an effort to regenerate Everglades tree islands and wet prairie communities, but was largely unsuccessful (See Worth 1983,1988).

Major Plant Communities of WCA-1. WCA-1 contains a spatially complex mosaic of wet prairies, tree islands, aquatic sloughs and cypress forests that represent the last remaining examples of native, northern Everglades habitat in South Florida. High species diversity and spatial complexity are the outstanding features of WCA-1. The area is characterized by numerous small tree islands ranging in size from 0.01 to 100 acres, surrounded by bands of sawgrass *(Cladium jamaicensis)* vegetation, in a matrix of wet prairie and aquatic slough communities. Typical tree island vegetation consists of dahoon holly *(Ilex cassine)*, red bay *(Persea borbonia)*, wax myrtle (*Myrica cerifera*), coco plum *(Chrysobalanus icacao)* and numerous species of ferns, orchids and epiphytes (Maffei, 1989).

The refuge contains numerous wet prairie and aquatic slough communities found in other areas of the Everglades. These wet prairie communities consist of spike rush (*Eleocharis cellulosa*), maiden cane *(Panicum hemitomon)*, bladderwort *(Utricularia* spp.), and various water lilies. Aquatic slough communities also contain extensive periphyton-bladderwort communities that are unique in comparison to other areas of the Everglades in that they contain algal species that are characteristic of acidic, soft water conditions (Swift, 1981).

Tree islands, or bay heads, are abundant throughout most of WCA-1 with the exception of the southern portion of the refuge. Aquatic sloughs are most often associated with lowest elevations within the marsh that generally hold standing water longer than all other habitats. Tree islands are located in areas that have higher elevations and the shortest hydroperiods.

The dominant factors influencing the development of WCA-1's complex vegetative patterns have been hydrologic regime (hydroperiod), historical flow patterns, low nutrient conditions and fire (Richardson and Kitchens, 1987).

In addition to hydroperiod and water levels, land elevation or topography (**Figure 21**) also play a significant role in determining the alignment of vegetation patterns and the distribution of wildlife within the refuge as well as influencing water movement and the water storage capacity of the marsh. Satellite imagery shows the effects of historical sheet flow patterns on the orientation of the refuge's numerous tree island and aquatic slough vegetation which are typically oriented in a north-south direction, parallel to historic flow patterns (Richardson and Kitchens, 1987). These flow patterns have been severely altered, or no longer exist within the WCAs due to impoundment of the marsh for regional flood control and water supply purposes. In 1965, a joint study by the USCOE, the District (then known as Central & Southern Florida Flood Control District), and USFWS collected data on land elevations, vegetation and water movement within the refuge, and prepared a generalized vegetation map showing nine separate vegetation zones for the area (**Figure 22**).

Enclosure of WCA-1 by levees and canals has eliminated historical sheet flow patterns within the refuge, dramatically altering the hydroperiod characteristics of certain areas of the marsh. Impoundment of the southern, lower elevations of WCA-1 has left this area flooded for long periods of time, while allowing more frequent drying of the extreme northern portion of the marsh (Pope, 1987). Areas which have experienced shortened hydroperiods have experienced vegetation shifts to woody vegetation (wax myrtle and willow) while the lower elevations have experienced shifts to more aquatic flora. Analysis of vegetative patterns in the early 1970s (USFWS, 1972) indicated that plant communities that were located at ground elevations below 14.0 NGVD experienced conversion to aquatic habitats, resulting in

Figure 21. Topographic Map of Water Conservation Area 1.
(Source: Richardson and Kitchens, 1987, Florida Cooperative Fish and Wildlife Research Unit, Gainesville, Fl.)

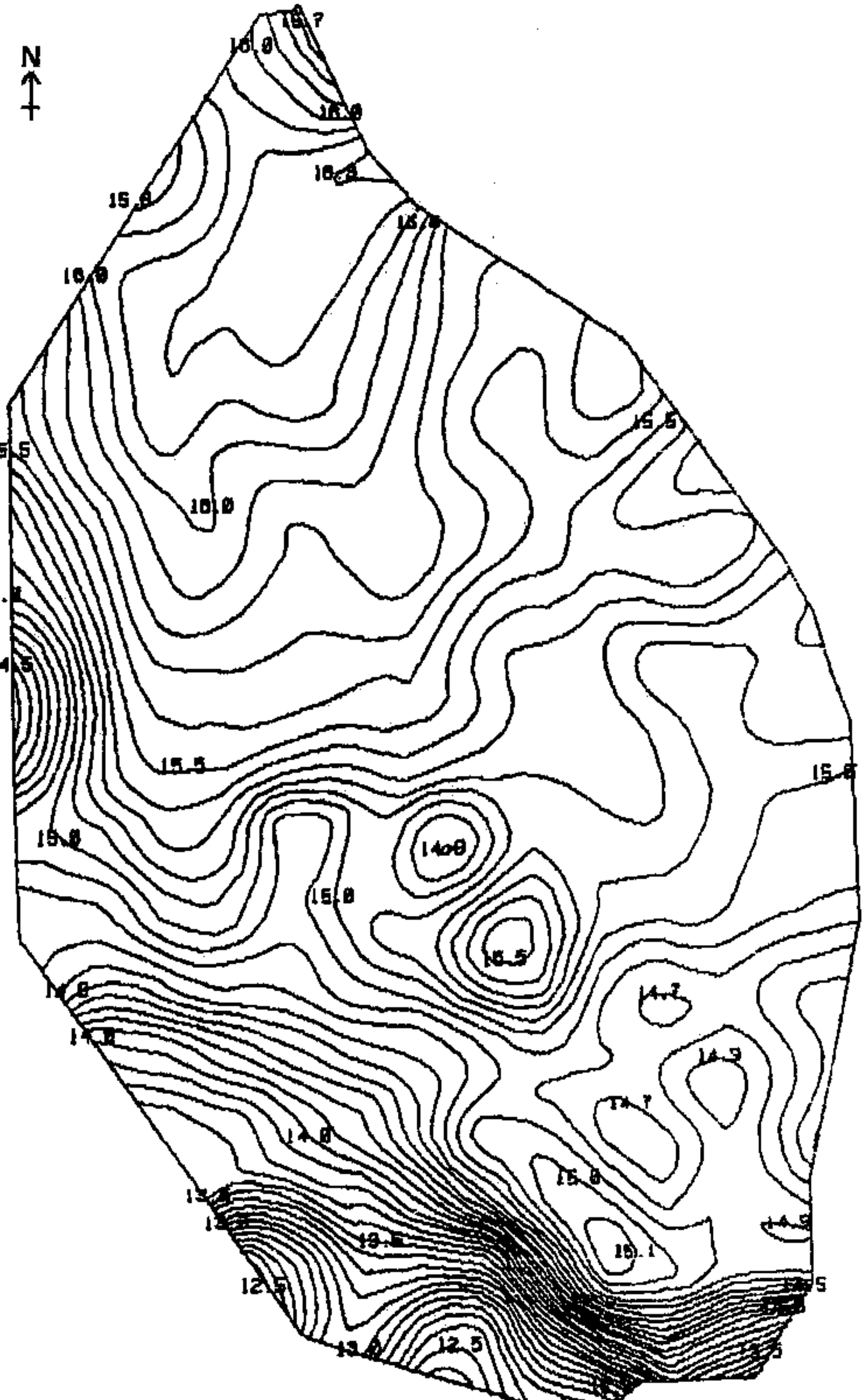
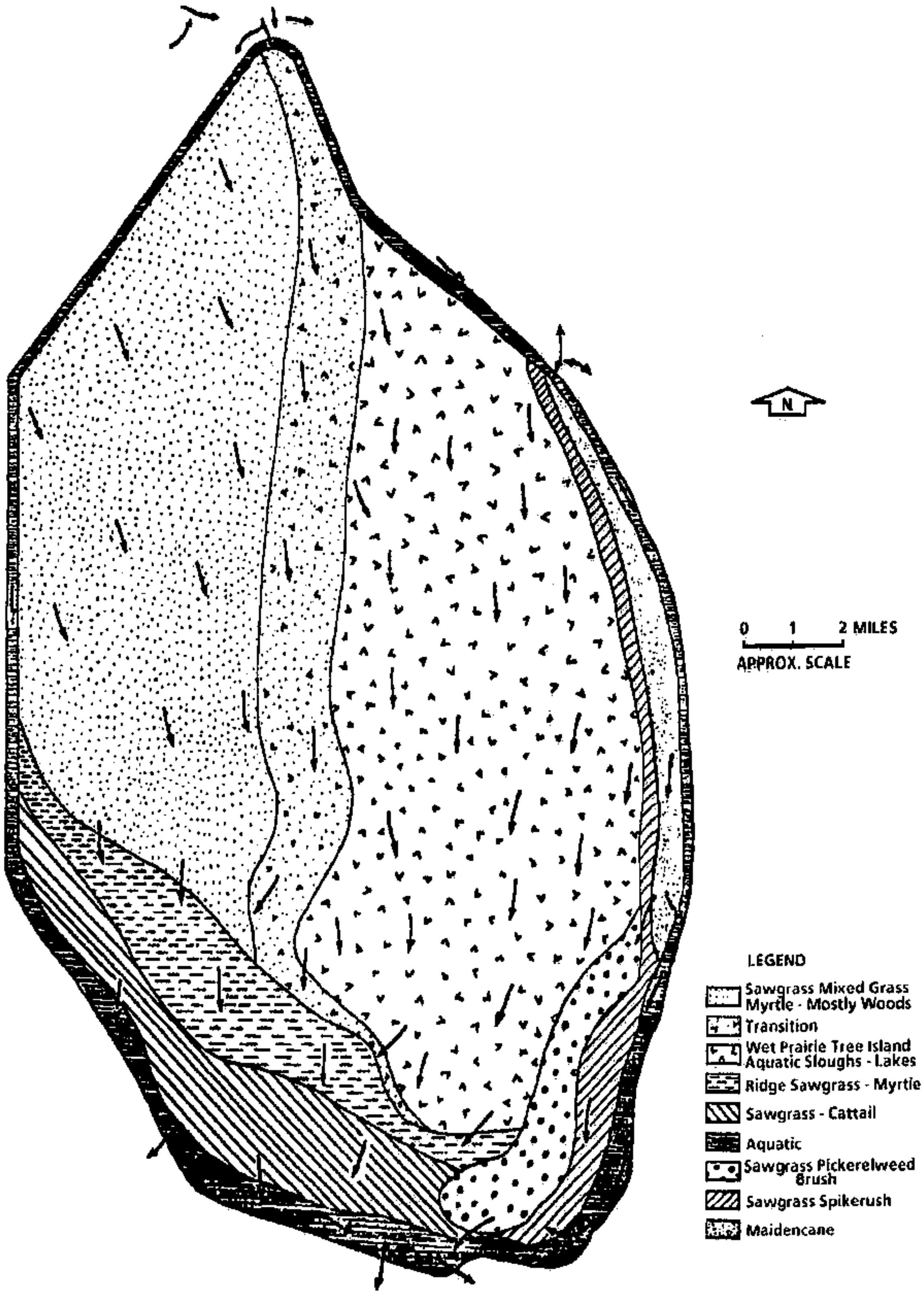


Figure 22. Summary of Major Vegetative Zones within WCA-1



an increase in the abundance and distribution of several nuisance species such as hydrilla (*Hydrilla verticillatum*), water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*) and cattail (*Typha* spp.) (**Figure 22**). These observations in vegetation change at the southern portion of the refuge are confounded by the influence of nutrient-enriched EAA drainage waters which enter WCA-1 through pump station S-5A and S-6. Nutrient-enrichment of these waters may also play a major role in determining the vegetation characteristics of the southern portion of the refuge. Marsh elevations above 14.0 NGVD comprised about 75 percent of the refuge and represented the most important sectors of the marsh for utilization by Everglades wildlife. These areas were characterized as wet prairies, tree islands and sawgrass-mixed habitats (USFWS, 1972).

A narrow swath of disturbed vegetation extends around the perimeter of the refuge. This disturbed vegetation includes giant cane (*Phragmites communis*), cattail, willow, herbaceous growths such as flag (*Thalia* spp) and smartweed (*Polygonum* spp) as well as floating aquatic plants such as water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*) and pennywort (*Hydrocotyle umbellata*). The refuge also contains a 400-acre cypress (*Taxodium distichum*) swamp, as well as three water management impoundments located on the eastern side of the refuge (Compartments A, 362 acres; Compartment B, 85 acres; and Compartment C, 276 acres), and Compartment D (1,300 acres) located on the western side of WCA-1 (USFWS, 1984).

Everglades plant communities are thought to have developed within a phosphorus-deficient ecosystem with the majority of nutrients derived from direct rainfall. Native vegetation communities were well adapted to surviving under these low nutrient conditions as well as seasonal fluctuations in water level, drought and fire (Steward and Ornes, 1975a). Native sawgrass communities grow well in waters that contain low, concentrations of nitrogen, phosphorus, potassium and copper . Limited quantities of available phosphorus in surface waters, in the organic soils and in sawgrass vegetation indicates that phosphorus is very rapidly cycled within this ecosystem (Steward and Ornes, 1975a). As a result, limited amounts of phosphorus are available in surface waters with the majority of phosphorus tied up in organic peat sediments and living vegetation. Similar trends of low phosphorus supplies have been observed for interior WCA-1 surface waters and within Everglades periphyton communities (Swift and Nicholas, 1987).

Cattail Distribution in WCA-1. The USFWS report (LOTAC-II,1988) that a number of vegetative changes have occurred within WCA-1 since construction of the West Palm Beach and Hillsboro canals in the early part of this century. Until 25 or 30 years ago, these changes had been small and were primarily a result of hydroperiod change caused by canal construction and impoundment of the marsh,as shown in the following quotations from Richardson (Florida Cooperative Fish and Wildlife Research Unit) as cited in LOTAC-II,1988:

> "Water quality problems in the refuge didn't begin to show up until the 1970s. As late as 1969, there was little or no cattail...in the south end of the refuge. ... Current studies being conducted by the University of Florida Cooperative Fish and Wildlife Research Unit indicate that as much as 6,000 acres of the refuge have been converted to cattail."

The report goes on to say that cattail expansion in WCA-1;

> "... is a direct response to nutrient-laden water being pumped into the refuge. Studies indicate that as much as 20,000 acres may be in danger of being converted to cattail. The combination

of hydroperiod change with the nutrient inflows are placing the whole south end of the refuge in jeopardy of being converted to cattail."

Review of aerial photography studies (USFWS, 1952) that were conducted in the early 1950s suggests that relatively little cattail was present on the refuge prior to the area being impounded by canals and levees (see also Givens, 1956). Analyses performed by the USFWS in 1952 recorded four major plant community types or vegetation "zones" existing on the refuge as listed in Table 12. Cattail was not identified as either a major or minor component of the refuge's vegetation during the early 1950s (USFWS, 1952; Givens, 1956). By 1960, the refuge was completely

Table 12. Vegetation analysis of major plant community types found in WCA-1 as determined from aerial photography, January, 1952.

Vegetation Cover Type	Acres	Percent
1. Sawgrass/ Wax Myrtle		
a. Sawgrass with little wax myrtle	31,800	22%
b. Wax myrtle/sawgrass and wax myrtle-dahoon holly	28,400	20%
c. Mixed grasses	9,700	7%
Subtotal	69,900	49%
2. Wet Prairie Community		
a. Typical "white grass" (*Rhynchospora traceyi*) flats	45,500	32%
b. Maidencane (*Panicum hemitomum*) Flats	4,440	3%
Subtotal	49,900	35%
3. Tree Islands and Bay Heads		
Subtotal	16,900	12%
4. Aquatic Sloughs		
a. Water Lily (*Nympheaea* sp.) sloughs	2,800	2%
b. Pickerel weed (*Pontederia* sp.)	2,500	2%
Subtotal	5,300	4%
TOTAL	142,000	12%

USFWS, 1952.

encircled by a canal and levee system with controlled water levels. Stieglitz (1962, 1964) reported the first account of cattail infestations on the refuge;

"Recent drought conditions [1962] appear to have been very favorable for cattail growth as this species is currently extending its' range in the refuge interior. Stands are rather scattered and thin at present, but the spread is constant. The most serious infestations exist on the south end of the refuge, adjacent to the Hillsboro canal. ... Cattail has also been noted around the peripheral canals ... and at numerous other sites within the refuge interior. The plant is well distributed over the refuge, and it is only a matter of time before actual habitat losses occur .... Approximately 425 acres of cattail, principally on the south end of the refuge, were treated by helicopter [using herbicides] between May 17-25, 1962. ... I recommend that a concerted cattail control project be initiated next spring" (Stieglitz, 1964).

Additional vegetation studies were conducted within the refuge's perimeter from 1963-1964 (Stieglitz, 1964). These studies also documented the presence of cattail along the refuge's perimeter and southern boundaries. Analysis of vegetation data collected along a transect established in the southwest corner of the refuge immediately north of the Hillsboro canal (Transect "C") revealed that cattails comprised about 5 percent of the community based on a percentage species composition. Cumulative analysis of the vegetation occurring along three transects located on the southeast, east and southwest perimeter (Transects A, B and C) of the refuge showed that cattail comprised about 1.1 percent of the total vegetation, based on percent species composition (Stieglitz, 1964).

An aerial survey of all peripheral areas of the refuge, including spot checks of the interior, was flown on August 31, 1965 in an effort to identify the growth trends of nuisance weeds (water hyacinth, alligator weed and water lettuce) that were present on the refuge (Stieglitz, 1965). An administrative decision was made to focus study efforts on the above three species, although cattails, maidencane and willow were also considered important "pest species" present within WCA-1. Results of the aerial survey documented that cattails were present in the extreme southern portion of the refuge (north of S-10C), as well as along the interior southwest portion of the refuge extending from S-10D north to pump station S-6 (Stieglitz, 1965).

In 1972, the USFWS issued a report concerning a possible revision of the water regulation schedule for WCA-1. This report contained an analysis of the area's topography and vegetation patterns present on the refuge. Vegetation lying below 14.0 ft. msl (NGVD) were identified as having the most profound changes; namely conversion to aquatic habitat. The vegetation most often associated with this zone includes water lily, pickerel weed, spatterdock and other deep water species (USFWS, 1972). The report also identified a number of vegetative changes that were thought to be associated with the more aquatic situations:

> "The vegetation change in the area north of the Hillsboro Canal from sawgrass to cattail to submergent aquatic vegetation now dominated by egeria [probably hydrilla] has been most dramatic. Accompanying this change has been an increase in the cattail zone from the Hillsboro canal northward along the canal associated with L-40 to the refuge headquarters. This zone has increased not only in distribution, but in width and progression toward the interior of the refuge from the canal bank" (USFWS, 1972).

The report also identifies concerns about the increase of "undesirable" aquatic plants on the refuge such as water hyacinth and egeria [hydrilla] and cattail USFWS, 1972, page 15). The 1972 report did not attempt to provide a quantitative estimate of as to the total are subject to invasion by these undesirable species, however the report did include a map which identified an area in the south/south-west portion of the refuge which was characterized as sawgrass- cattail (**Figure 22**). Conversion of **Figure 22** to a computer AUTOCAD drawing by District staff shows the sawgrass-cattail vegetation class to represent about 9,600 acres or about 6.6 percent of the WCA-1 marsh.

Morton's (1975) review paper on the economic use of cattails cites a personal communication with K.K. Steward (Research Plant Physiologist, USDA, Ft. Lauderdale, Fl.);

> "In some areas of the Florida Everglades, cattails are multiplying at the expense of other vegetation. There is a massive encroachment of cattails in the Florida Flood Control Conservation Area No.1 [WCA-1] which is attributed to increased water depths unfavorable to sawgrass and to higher nutrient levels resulting from agricultural operations" (Morton, 1975).

The above paper provides no quantitative information concerning cattail distribution or water quality conditions within WCA-1 which support the above statement.

The report entitled Fire Management Plan for the Loxahatchee National Wildlife Refuge (USFWS, 1984) includes the following comments regarding the distribution of cattails on the refuge:

> "At the southern end of the refuge, the hydroperiod has been lengthened and sloughs have been replaced by shallow lake communities with cattail (*Typha* sp.) and/or submerged floating plants. ... Treatment Area 4 [southern portion of the refuge] has the highest water levels and much of it is permanently flooded. It is made up of roughly 50% sawgrass and 50% sloughs. The southern edge is lined with dense cattail stands. ... Treatment Area 5 [southwest portion of the refuge] is made up mostly of sawgrass and sawgrass brush communities, broken up by sloughs and wet prairies. Tree islands extend into the eastern half and a huge cattail stand lines part of the western edge. ... This area may be more susceptible to surges in water levels than some other areas, due to its location southeast of the S-6 pump station" (USFWS, 1984).

The USFWS (1984) report also provides a copy of the 1972 USFWS vegetation map shown in **Figure 23** which characterizes the southwestern portion of the refuge as a"sawgrass-cattail vegetation zone" (USFWS, 1984, Figure 3).

Classification of the refuge's vegetation was recently reevaluated using satellite image data provided from a SPOT satellite pass obtained on April 4, 1987 (Richardson and Kitchens, 1987). The satellite image data has a resolution capability of 20 meters in the multispectral bands (green, red, and near infra-red) and a 10 meter resolution in the panchromatic band An initial set of 25 spectral signatures were reduced to a final set of 18 signatures to classify the image. The final image produced contained 18 vegetation community types using the supervised classification as shown in **Table 13**, columns B-D (Richardson and Kitchens, 1987). Summary of these 18 vegetation types into seven more general vegetation classes was performed by SFWMD staff as shown in **Table 13**, column A. **Table 13** shows that aquatic slough/wet prairie communities represent the dominant community type found on the refuge while sawgrass dominated community types ranked second. The brush category (wax myrtle on tree islands and in wet prairies) ranked as the third largest classification while cattails, tree islands, willow and open water ranked as the fourth, fifth, sixth and seventh most abundant community types present. In 1988, Richardson (LOTAC-II, 1988) further refined the original 18 spectral signatures reducing them to the six vegetation classes shown in **Table 14**.

Tables 13 and **14** indicate that in 1987, the refuge contained from 5,386 to 5,726 acres of cattail comprising about 4 percent of the refuge's vegetation. These data reflect both the distribution of dense cattail stands located at the edge of the refuge (1,746 acres), cattail stands located away from the canal (1,856 acres) and sawgrass stands that were being invaded by cattail (2,124 acres) (**Table 13, column B**).

Annual reports submitted to the refuge by the Florida Cooperative Fish and Wildlife Unit (Richardson and Kitchens, 1986a, 1986b, 1986c, 1987, 1988; Pope, 1989 draft report) found a correlation between nutrients extracted from samples of refuge peat soil and the distribution of water hyacinths, smartweed, water fern (*Salvinia* sp.) and cattail vegetation found on the refuge. Although this work did not directly sample surface water nutrient chemistry, it concluded that the refuge's vegetation patterns appear to be primarily due to anthropogenic alterations of hydroperiod and water quality (Pope, 1989). Initial data collected to date indicate that areas that have experienced some invasion by cattail tend to have higher

Table 13. . Results of 4 April 1987 SPOT Satellite Supervised Vegetation Classification Map for the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Richardson and Kitchens, 1987).

Vegetation Class No. (Column A)	Vegetation Type (Column B)	Acres	Percent
Sawgrass			
1	High density sawgrass	948	0.7
3	Sawgrass	18,132	13.0
4	Brush / sawgrass (primarily saw grass, large amounts of wax myrtle)	21,915	15.7
15	Sawgrass/brush (mostly sawgrass)	2,548	1.8
16	Sawgrass ridges (higher elevations)	6,214	4.5
	Subtotal	49,757	35.7
Tree Islands			
5	Tree Islands (low stature trees)	2,387	1.7
7	Tree Islands (high stature trees)	867	0.6
	Subtotal	3,254	2.3
Slough/ Wet Prairie			
6	Dense Wet Prairie	46,544	33.4
9	Sparse Wet Prairie	9,934	7.1
12	Slough / sparse wet prairie	272	0.2
	Subtotal	56,750	40.7
Brush			
8	Brush (small clumps in wet prairie)	4,771	3.4
14	Brush / Tree Island	16,467	11.8
	Subtotal	21,238	15.2
Willow			
13	Willow / brush	1,160	0.8
17	Willow along canal edge	1,167	0.8
	Subtotal	2,327	1.7
Cattail			
10	Cattail closest to canal	1,746	1.3
18	Cattail (further from canal)	1,856	1.3
2	Sawgrass with invasion by cattail	2,124	1.5
	Subtotal	5,726	4.1
Open water			
11	Open water (canals)	282	0.2
Total		139,334	100.0

Source: Column A summarized into 7 classes by SFWMD, Columns B - D from Richardson & Kitchens, 1987, pgs 9-10.

* = Determined from a set of 18 spectral signatures.

concentrations of nutrients in the water column and substrates than areas where cattails are absent (Richardson and Kitchens, 1988; Pope, 1989).

Richardson (as cited in LOTAC-II, 1988) suggests that a direct relationship exists between increases in surface water nutrient concentrations and the expansion of cattails in WCA-1. This supposition is based on little direct information which establishes a significant correlation between increases in surface water nutrient concentrations over time and cattail expansion within WCA-1, although similar information exists from studies conducted in WCA-2A and ENP that support the refuge's concern that nutrients threaten the ecology of the Everglades ecosystem. Although the presence of cattail communities was first noted in 1962-1964 (Steiglitz, 1965), the first mapping efforts to define the distribution of cattails in WCA-1, were conducted in 1972 (USFWS, 1972). This map was also used in a later report to

Table 14. Distribution of Major Plant Communities in WCA-1 as Determined by SPOT Satellite Imagery, 4 April,1987 (from Richardson, J. as cited in LOTAC-II, 1988).

Vegetation Class	Acres	Percent
Aquatic Slough/ Wet Prairie	51,996	36.1
Sawgrass	49,786	34.7
Brush	29,554	20.6
Tree Islands	5,783	4.0
Cattail	5,386	3.8
Willow	1,168	0.8
Total	143,673	100

Source: Richardson J., Florida Cooperative Fish and Wildlife Research Unit as cited in LOTAC-II, 1988.

represent the distribution of cattail within WCA-1 in the early 1980s (USFWS, 1984). Subsequent digitizing of the 1972 map by the District indicated that the area of mixed sawgrass and cattails occupied near 9,000 acres. By contrast, a recent 1987 mapping effort, based on satellite imagery, indicated that communities of cattails and cattails mixed with other vegetation occupied approximately 5,700 acres of the refuge in 1987 (Richardson and Kitchens, 1987).

What can be said from the limited data available is that: (a) cattails as well as other aquatic vegetation became established in the south end of WCA-1 during the early 1960s after the construction of perimeter canals and levees which resulted in stabilized, deep water conditions at the south end of the refuge. These hydrological changes were associated with conversion of Everglades habitat below 14 ft. NGVD to aquatic slough communities (USFWS, 1972); (b) Over the last thirty years, development of agriculture within the EAA has increased nutrient loadings to WCA-1 (see WCA Water Quality section of this report) and may have also impacted peripheral areas of the marsh exposed to higher levels of nitrogen and phosphorus derived from upstream agricultural operations, (c) Review of the available data shows that no clear picture emerges which identifies the direct cause of the alleged increase in cattails in WCA-1. A number of factors influence the establishment of cattails in the Everglades. These include, physical disturbance of underlying soil profile (by canal construction activities or by alligator nest building), proximity to seed sources, fire, hydrologic changes and the availability of nutrients. (d) Existing data has not yet established that a significant statistical relationship exists between increases in surface water nutrient concentrations or loading rates and cattail distribution in WCA-1, separate from other causative factors.

Introduced Exotics: Invasion by exotic vegetation is a growing problem on the refuge, within the cypress swamp and within the refuge's water management impoundments. Melaleuca *(Melaleuca quinquenervia)* and Brazilian pepper *(Schinus terebinthifolius)* are both rapidly spreading along the perimeter of the refuge and into the interior marsh. Melaleuca is currently found in every section of the refuge. In 1965, few exotic trees were present. Currently, tree island and sawgrass communities along the eastern portion of the refuge are most impacted. In 1988, total coverage of melaleuca on the refuge was estimated to be near 4,000 acres (USFWS, 1989).

Major Plant Communities of WCA-2. Detailed descriptions of the plant communities which existed within the WCA-2A prior to impoundment of the area are provided by Davis (1943a,b) and Loveless (1959). Vegetation that was characteristic of the area prior to impoundment included tree islands, sawgrass and extensive communities of beakrush (*Rhynchospora tracyi*), maidencane (*Panicum hemitomon*) and spikerush (*Eleocharis cellulosa*). The wet prairie communities occurred primarily in the central and eastern portions of WCA-2. A generalized 1956 vegetation map of WCA-2 showed more than 50 major tree islands in what is now WCA-2A (SFWMD, 1978). During the 1960s and 1970s, WCA-2A was managed as a regional water storage area which resulted in prolonged high water levels and eliminated the natural Everglades hydroperiod. The water regulation schedule for WCA-2A during this period ranged seasonally between 13.0-14.5 ft. NGVD (**Figure 19**). Stabilization of water levels resulted in the elimination of the natural flood-drought cycle. This stabilization, combined with an increased frequency of flooding, increased water depths, reduction of the frequency of fire and high nutrient loading associated with agricultural runoff, produced a number of ecological changes. Examples of such changes include the elimination of wet prairie communities, drowning of tree islands, loss of sawgrass communities along slough edges, accumulation of a flocculent layer of plant detritus (up to 14 inches deep) in sloughs causing high oxygen demand and periodic fish kills, loss of wading bird feeding habitat (Dineen, 1972, 1974). Major plant communities in WCA-2A now consist of remnant drowned tree islands, open water sloughs and large expanses of sawgrass, and sawgrass intermixed with dense cattail (*Typha domingensis*) stands.

In recognition of these problems, the SFWMD initiated several experimental drawdown studies of WCA-2A for the purpose of stimulating more natural drying conditions that would promote the regrowth of wet prairie vegetation and tree island communities. An experimental drawdown was conducted in 1973 which allowed WCA-2A to dry out for 71 days before summer rains refilled the area. Many areas of the marsh failed to dry out due to the late timing of the drawdown. Some success was observed in consolidating the flocculent layer of organic detritus as well as stimulating the regrowth of a few species of wet prairie and woody tree island vegetation (Dineen, 1974). Wading birds (white ibis, herons and wood storks), migratory waterfowl and snail kites were observed utilizing WCA-2A on a more frequent basis during the drawdown as compared to years when the higher water level schedule was in effect (Kushlan, 1974).

In 1980, a second attempt was initiated to achieve a drawdown of the area over a four-year period (1980-1984). The second drawdown reduced the regulation schedule from 13.0-14.5 ft. NGVD to 9.5-12.5 ft. NGVD. The initial 1980-81 drawdown coincided with a regional drought. Concerns for regional water supplies suspended the drawdown during 1982 until the late dry season. The result was that only a partial drying of the marsh was accomplished. The dry seasons of 1983 and 1984 were unusually wet and prevented the planned drying of the system. In large part due to extreme climatic conditions, the drawdown effort overall was only partially successful. Lowered water levels created favorable conditions that allowed for some expansion of wet prairie communities and increased sawgrass densities (Worth, 1988).

Remaining tree islands are found primarily at higher ground level elevations which are located in the northwest corner of WCA-2A. Remnant (drowned) tree islands, dominated primarily by willow, are found scattered throughout the central and southern sections of WCA-2A (**Figure 23**).

Cattail Distribution in WCA-2A. Concerns have focused on the problems of nutrient-enrichment and cattail expansion in the northwest portion of WCA-2A. The increase in cattails in WCA-2A over time is supported largely by long-term field

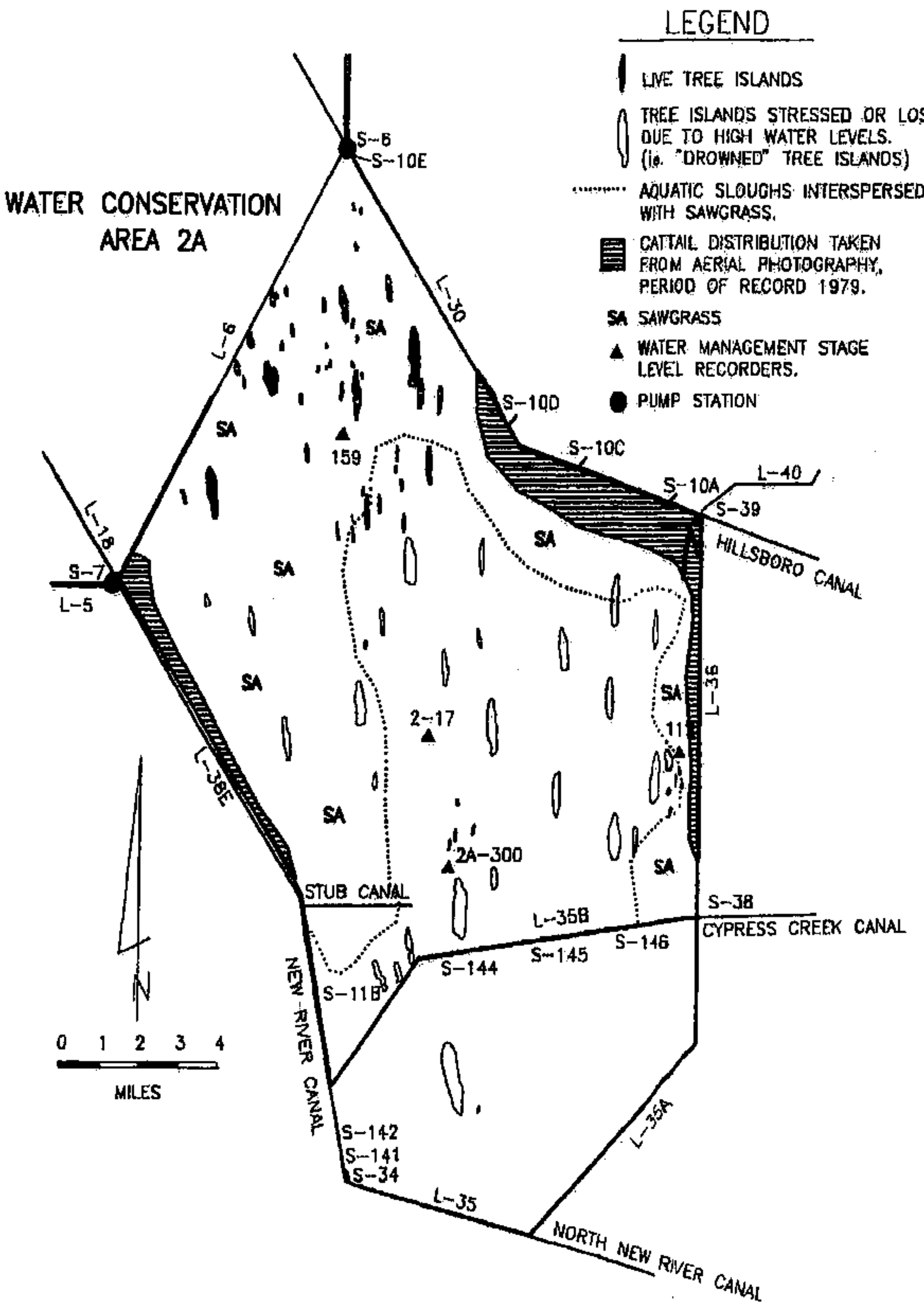


Figure 23. Dominant Plant Communities Prior to Drawdown of WCA-2A, Period of Record, 1979

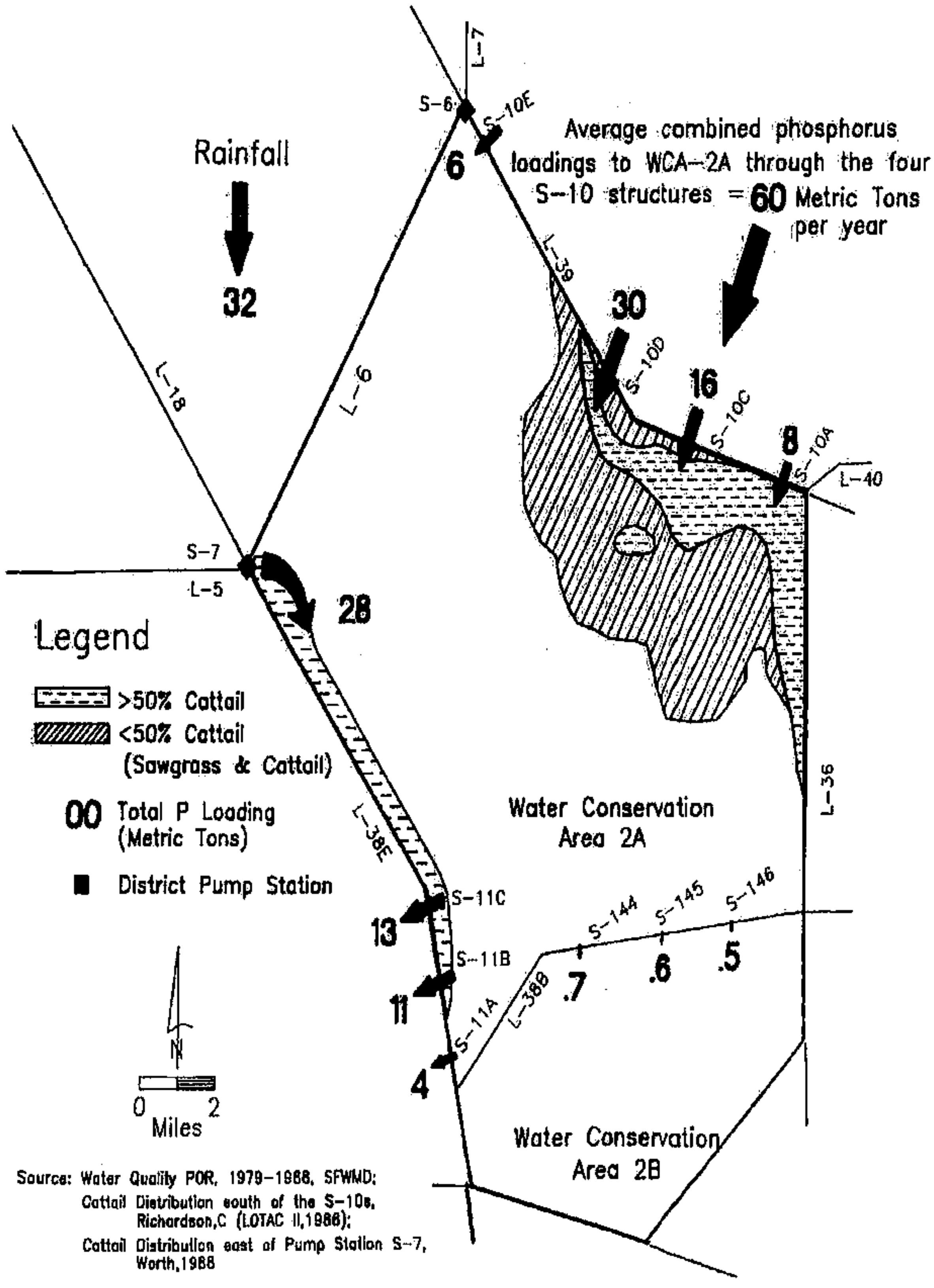
observations made by District scientists (Davis and Harris, 1978; Reeder and Davis, 1983; Davis, 1982, 1984 1989, 1991; Swift, 1981; Swift and Nicholas, 1987; Toth, 1987, 1988; Worth, 1983; 1988; Urban, 1984) who have conducted water quality and environmental studies within WCA-2A over the last dozen years (1977-1989). These researchers have noted an increase in cattail abundance downstream from District water control structures S-10C and S-10D in areas that were originally dominated by sawgrass, while cattail was typically observed as rare or absent. Field observations noting increases in cattail distribution also coincided with observed increases in surface water nutrient concentrations measured downstream from these two water management structures. District scientists have documented the existence of a defined nutrient gradient downstream of S-10C (Swift, 1981; Swift and Nicholas, 1987). A set of seven sampling points arranged in a straight line south of S-10C was established in 1978 and labeled "Transect B". High concentrations of nutrients existed at sites dominated by cattail (sites B-1 through B-3) while low concentrations of nutrients existed at sites dominated by sawgrass vegetation (Sites B-5 through B-7). In a follow-up study, conducted from 1980 - 1982, Swift and Nicholas (1987) reported that the nutrient gradient had shifted further south affecting the microbiology (periphyton community) of site B-5 located 3.7 km downstream of S-10C. These data provide evidence that nutrients had penetrated the marsh interior several kilometers further downstream than originally observed in 1978-1979.

The most current data available (Richardson, C. as cited in LOTAC-II, 1988, Planning Document) concerning the present distribution of cattails in WCA-2A is presented in **Figure 24.** This map shows 4,400 acres in which cattail represent more than 50% of the vegetation in coverage and 24,000 acres of mixed or scattered cattail (<50% coverage) present in the northeast portion of WCA-2A. Since this survey was conducted in the middle of a long-term regional drought, the species composition data presented in this study may be unrepresentative of average conditions due to extensive invasion by pigweed (*Amaranthus* sp.) and temporary thinning of cattails resulting from extremely dry conditions. **Figure 24** shows the relationship between the occurrence of cattail stands in WCA-2A and phosphorus loadings through the three S-10 discharge structures A similar relationship is noted downstream of pump station S-7 (**Figure 24**).

Several studies conducted within WCA-2A show that cattails out-compete sawgrass in their ability to uptake nutrients and increase cattail production during years of high nutrient inflows (Toth, 1988; Davis, 1991). Cattails are considered a high nutrient status species that is opportunistic and highly competitive, relative to sawgrass, in nutrient-enriched situations (Toth, 1988; Davis, 1991). Davis (1991) concluded that both sawgrass and cattail increased annual production in response to elevated nutrient concentrations, but that cattail differed in its ability to increase plant production during years of high nutrient supply.

Introduced Exotics. Infestation of melaleuca in WCA-2A is considered to be relatively sparse (scattered single or small clumps of outlier trees) and currently comprise less than 10 percent (<11,000 acres) of the sawgrass marsh (Melaleuca Task Force, 1990). Low numbers of trees are thought to be related to higher water levels that were maintained in the area prior to 1980 as well as a District experimental melaleuca control program. Existing melaleuca trees are generally restricted to higher ground level elevations such as tree islands and sawgrass ridges (Worth, 1983). Control of melaleuca was initiated in 1980 as part of a larger environmental study to evaluate the effects of a drawdown of WCA-2A. Efforts were directed at eradicating or controlling the existing melaleuca seed sources to prevent further spread as a result of the drawdown effort (Worth, 1983, 1988).

Figure 24. Average Total Phosphorus Loadings and Cattail Distribution in WCA-2A.



Vegetation in WCA-2B. Due to the highly permeable nature of the aquifer underlying WCA-2B, it has been difficult to maintain historical water levels within this impoundment. As a result, no water regulation schedule is currently maintained for WCA-2B although the area should not be allowed to exceed 11.0 ft. NGVD unless the outlet structure is open. Impoundment of WCA-2B by construction of the L-35B in 1972 resulted in a lowered water table and a shortened hydroperiod, setting the stage for melaleuca invasion throughout WCA-2B. Since 1980, the hydrology of WCA-2B has changed considerably. Drawdown efforts in WCA-2A during the 1980's resulted in increased volumes of water being diverted to WCA-2B. These efforts have helped somewhat to slow down the invasion of melaleuca.

In the south end of WCA-2B there still exists an extensive wet prairie community (*Eleocharis cellulosa* and *Panicum hemitomon*) which has been reported to serve as a important feeding area for wood storks, snail kites and other wading birds over the last several years. Approximately 30 snail kites were observed utilizing the south end of WCA-2B in 1987 (Discussion April 1989 with Mark Robson, FGFWFC, West Palm Beach, FL.)

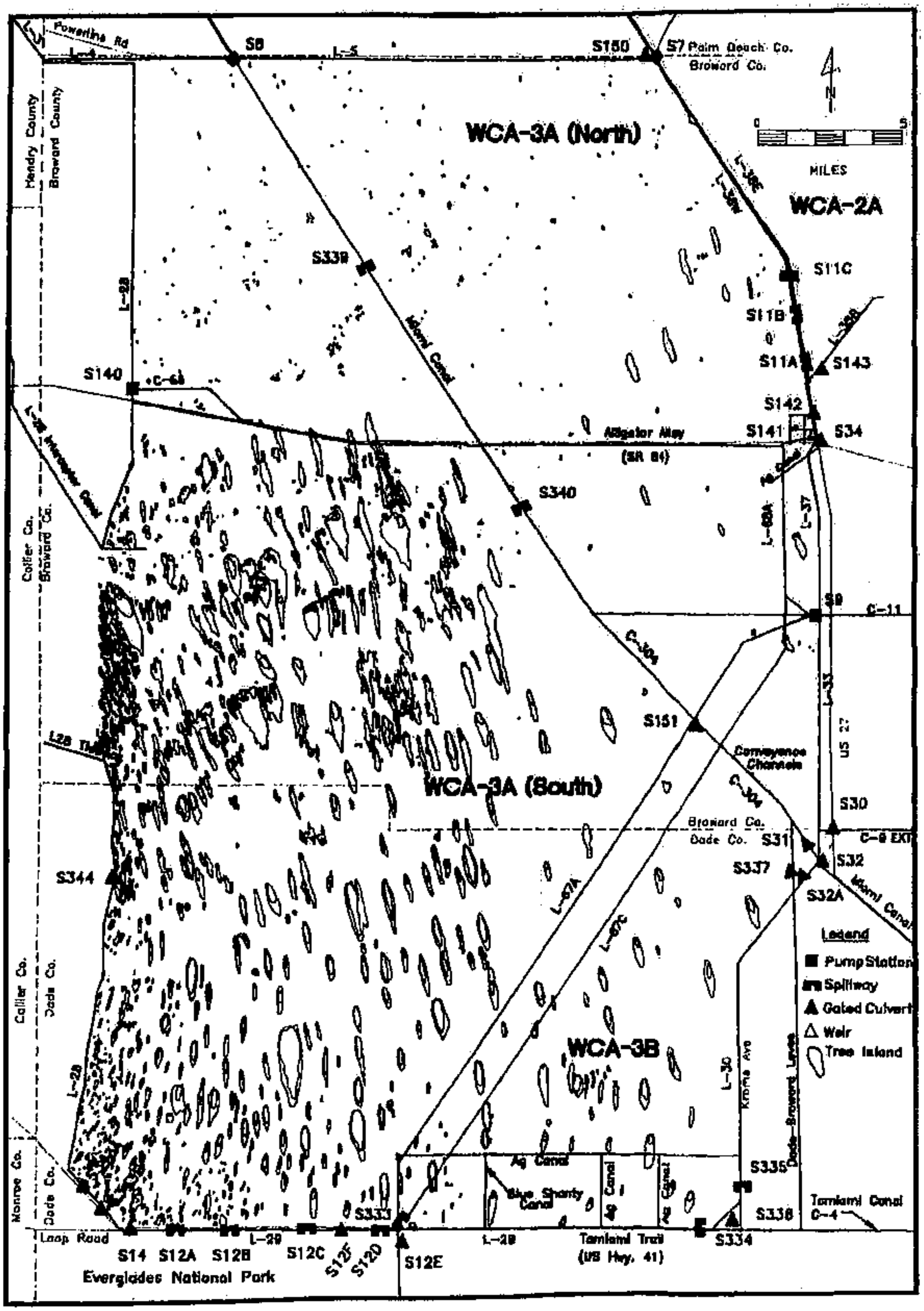
Introduced Exotics: Heavy infestations of melaleuca (large heads and solid forests) occur throughout WCA-2B (Melaleuca Task Force, 1990) and threaten to dominate the marsh within the next several decades. Recent estimates (1990) indicate that about one-quarter of WCA-2B (10,000 acres) is currently heavily infested by this introduced exotic (Melaleuca Task Force, 1990).

Major Plant Communities of WCA-3. Figure 25 provides a map showing the general distribution and orientation of tree islands and other water management features within WCA-3A and WCA-3B. The original vegetation communities of WCA-3 were first described by Davis (1943a,b) and Loveless (1959). Many areas of WCA-3 still contain vast tracts of Everglades habitat consisting of tree islands, sawgrass marsh, wet prairies and aquatic sloughs that are very similar in appearance to the descriptions provided by these early studies. However, a number of major changes have occurred as a result of canal and levee construction and impoundment of the area.

WCA-3A North. The community structure and species diversity of Everglades vegetation located north of Alligator Alley (WCA-3A North) is very different from the wetland plant communities found south of the trans-Everglades highway (WCA-3A South). Improvements made to the Miami Canal and impoundment of WCA-3A by levees have over-drained the north end of WCA-3A and shortened its natural hydroperiod (**Figure 20**). These hydrological changes have increased the frequency of severe peat fires which have resulted in loss of tree islands, aquatic slough and wet prairie habitat that were once characteristic of the area prior to construction of the C&SF project. Today, northern WCA-3A is largely dominated by sawgrass and lacks the natural structural diversity of plant communities seen in southern WCA-3A.

Over-drainage of the northwestern portion of WCA-3A has allowed the invasion of a number of terrestrial species such as salt bush (*Baccharis halmifolia*), dog fennel (*Eupatorium capillifolium*) and broom sedge (*Andropogon* spp.). Melaleuca has become well established in the southeastern corner of WCA-3A North and is spreading to the north and west. The FGFWFC is currently evaluating the

Figure 25. Location of Major Tree Islands and Water Management Structures in WCA-3A and WCA-3B.



spread of this introduced exotic plant within WCA-3A North (Discussion April, 1989 with John Ault, FGFWFC, West Palm Beach, FL.).

WCA-3A South. Everglades vegetation located in the central and southern portion of WCA-3A South probably represents some of the best examples of original, undisturbed Everglades habitat left in south Florida (**Figure 25**). This region of the Everglades appears to have changed little since the 1950's and contains a mosaic of tree islands, wet prairies, sawgrass stands and aquatic sloughs similar to those reported by Loveless (1959).

Although the majority of vegetation within WCA-3A south can be described as typical Everglades habitat, several localized problem areas exist. Construction of Alligator Alley (State Road 84) in 1967 cut off sheet flow to the central and southern portions of WCA-3A. The construction of canals and the roadbed has resulted in excessive drainage of the marsh both north and south of the highway. Areas of the marsh located several miles south of the highway and west of the Miami Canal have experienced a shortened hydroperiod, and an increased frequency of peat fires. Severe peat fires during the droughts of 1981, 1985 and 1989 have burned tree islands down to bare rock in many places causing the loss of tree islands north and south of Alligator Alley as well as increasing soil subsidence rates in WCA-3A (Zaffke, 1983; Schortemeyer, 1980). Two environmental enhancement structures, S-339 and S-340 were constructed on the Miami Canal (C-123) in 1980 to divert canal water across WCA-3A north and WCA-3A south in an effort to prolong the marsh hydroperiod, increase water table levels and reduce flow rates to the south end of WCA-3A (Zaffke, 1983).

The east-central portion of WCA-3A South, located upstream from pump station S-9, has few tree islands and is comprised primarily of aquatic slough and sawgrass vegetation (**Figure 25**). District biologists have observed large stands of cattail existing in this general area. This area, located south of Alligator Alley and east of the Miami Canal, periodically experiences prolonged deep water conditions primarily as a result of S-11 inflows during the wet season. There are several canals which converge in this area, bringing inflows from the S-11s, and other upstream inflows influenced by agricultural drainage. The S-9 contributes a mix of urban and rural runoff from rapidly developing west-central Broward County. The multiple hydrologic connections to this area make it difficult to clearly identify specific sources of influences on vegetation patterns.

Apparent impacts to vegetation also have been noted in the western portion of WCA-3A; along C-60, located downstream from pump station S-140; and at the terminus of the L-28 Interceptor Canal.

Completion of L-29 across the southern end of WCA-3 in 1962 coupled with improvements to several major canals (Miami Canal, L-67A, L-29 and L-38W) interrupted the historic flow of water southward causing the ponding of water at the extreme south end of WCA-3A. This construction resulted in longer periods of inundation and relatively deeper water levels in the southern portion of WCA-3A as compared to the central portion of the marsh (**Figure 20**). These hydroperiod changes resulted in a loss of wet prairie habitat with an increase in aquatic slough communities which may have benefited snail kite populations in this area by providing favorable habitat for the production of apple snails, the primary food source of this endangered species.

Vegetation of WCA-3B: Plant communities within WCA-3B exhibit typical Everglades vegetation consisting of a mosaic of tree islands, wet prairies, sawgrass stands and aquatic slough communities. This area has changed little since the enclosing levees were completed in the early 1960s. Tree islands in this area however, are threatened by the invasion of melaleuca, which has become firmly established as a seed source within the Bird Road/Pennsuco wetlands located just east of WCA-3B in western Dade County.

Introduced Exotics: Rough estimates indicate that about half (300,000 acres) of WCA-3 contain light to moderate infestations (widely scattered outliers and small heads) of melaleuca (Melaleuca Task Force, 1990).

4. Wildlife Resources.

Macroinvertebrates. Macroinvertebrates represent an important component of the Everglades food web. However, relatively little published information exists concerning their distribution, species composition or abundance in the WCAs.

Previous Studies. Kolpinsky and Higer (1969), working in the marshes of Everglades National Park, first reported the importance of crustaceans to the Everglades food web. Such species as crayfish (*Procambarus alleni*), and the freshwater shrimp (*Palaemonetes paludosus*) as well as small forage fish represent a major component of the Everglades food web providing prey for larger fish, amphibians, reptiles and wading birds.

Much less information is available for the WCAs. A study conducted by the USGS in 1972-1973 sampled twelve canal and marsh sites in an effort to document the types of benthic organisms in the WCAs and to determine the extent which chemical and physical parameters affect their distribution and community structure (Waller, 1976). Ten of the 12 sites were located in WCA canals while only two sites (the 2-17 gage in WCA-2A, the 3-28 gage in WCA-3A) were located at interior marsh sites that were unaffected by canal water inflows. Results showed that benthic species diversity indices were low at all sites sampled and were considered to be representative of degraded water quality conditions. Physical factors such as depth, velocity of flow, substrate type and water level fluctuations were responsible for the observed low species diversity and high variability in the numbers of organisms present. Immature insects were the most prevalent forms encountered (55 percent) followed by annelids (oligochaetes and leaches, 21 percent), crustaceans (freshwater shrimp, *Palaemonetes paludosus)* and gastropods.

The most detailed information available for the WCAs is an unpublished study conducted by District biologists from 1979-1980 (Terczak, 1980, unpublished data). Samples collected from three sites in WCA-1, three sites in WCA-2A, and two sites in WCA-3A contained 82 species of invertebrates. Dipterans (chironomids and ceratopogonids) represented the dominant invertebrates present and apparently utilized periphyton and plant detritus as a food source. Dipterans (*Dasyhelia grisea* and *Chironomus* sp.) as group comprised over 50 percent of the fauna and represented a major food source for juvenile and forage-sized fish. Amphipods (*Hyalella azetcus*) (28 percent) and annelids (*Tubifex tubifex)* (11 percent) were the third and fourth most abundant groups, respectively. The amphipod, *Hyalella azetcus* and oligochaetes represented the most widely distributed groups of invertebrates. Other important invertebrates present were freshwater shrimp and crayfish (*Procambarus fallax* and *P. alleni),* which are prey species for wading birds.

Results of the study indicated that fewer numbers of species were present at the nutrient-enriched 2C site (the equivalent to site B-2, Swift and Nicholas, 1987) located in WCA-2A, downstream of the S-10C.

More recent data were collected by Reeder and Davis (1983), Urban (1984) and Davis (1991) downstream of S-10C in WCA-2A. Anoxic conditions at nutrient-enriched sites appeared to have caused a shift in the microbial communities that were responsible for decomposition of plant leaf litter. Litter microflora that could grow in the presence of oxygen appeared to be replaced by anaerobic bacteria at nutrient-enriched sites. Ramifications of such a shift on Everglades food chains are poorly understood but probably significant, since detrital food chains play important roles in many aquatic and wetland ecosystems (Reeder and Davis, 1983). Changes in communities of macroinvertebrates that colonized leaf litter included a reduction in species numbers, a near elimination of snails, elimination of isopods (*Asellus spp.*), and more than doubling of numbers of annelid worms (*Dero*) at nutrient enriched sites compared to background sites (Urban, 1984). The texture of organic sediments on the marsh floor changed from relatively compact, fibrous sawgrass sediment at background locations to flocculent, relatively fine, mush-like cattail sediment at nutrient-enriched sites (Davis, 1991).

Fisheries Resources. Dineen (1974) reported 43 species of fish indigenous to south Florida inhabiting the WCAs. The dominant forage fishes observed within the marshes and canals of the WCAs were mosquitofish (*Gambusia affinis*), the least killifish (*Heterandria formosa*) and topminnows which include the Florida flag fish (*Jordanella floridae*, and the bluefin killifish (*Lucania goodei*). Important predatory fish species included largemouth bass (*Micropterus salmoides*), several species of sunfish (*Lepomis* spp.), warmouth (*Lepomis gulosus*), bowfin (*Amia calva*), and gar (*Lepisosteus* spp.). **Table 15** provides a list of the most common fish species found within the Everglades WCAs.

There are two primary environments which support Everglades fish communities in the WCAs. These include: (1) the vast expanse of open water aquatic sloughs and wet prairie communities which comprise the majority of the study area, and (2) the deep water canal environments within the WCAs. While canals contain water throughout the year, many areas of the interior marsh experience seasonal drying. As a result, fish populations within both the marsh and canals fluctuate widely from season to season and year to year in response to changing water levels. The extensive canal system supports fish species that normally would not be common inhabitants of the Everglades marshes, but typically found in lakes. These fish included black crappie (*Pomoxis nigromaculatus*), catfish (*Ictalurus* spp.), and shad (*Dorosoma* spp.). In addition, canals with access to the Atlantic Ocean have permitted the migration of marine fish such as the Atlantic needlefish (*Strongylura marina*), American eel (*Anguilla rostrata*), snook (*Centropomus undecimalis*), and tarpon (*Megalops atlantica*) into some sections of the WCA canals. Four exotic freshwater species have successfully established reproducing populations within the three WCAs (F. Morello, FGFWFC, personal communication, 1989) including the oscar (*Astronotus ocellatus*), spotted tilapia (*Tilapia mariae*), walking catfish (*Clarias batrachus*), and the black acara (*Cichlasoma bimaculatum*). Impact of these exotics on the native fish inhabiting the WCAs is not currently known. The extensive canal system offers refuge for fish during drought conditions allowing for rapid repopulation of the marsh when water levels rise and also serves to increases the diversity of fish found in the WCAs.

Table 15. Common Freshwater Fishes of the Everglades WCAs.

Family	Scientific Name	Common Name
Amiidae	*Amia calva*	Bowfin
Anguillidae	*Anguilla rostrata*	American eel
Aphredoderide	*Aphredoderus sayanus*	Pirate perch
Atherinidae	*Labidesthes sicculus*	Brook silverside
Belonidae	*Strongylura marina*	Atlantic needlefish
Catostomidae	*Erimyzon sucetta*	Lake chubsucker
Centrarchidae	*Elassoma evergladei*	Everglades pygmy sunfish
	Enneacanthus gloriosus	Bluespotted sunfish
	Lepomis gulosus	Warmouth
	Lepomis macrochirus	Bluegill
	Lepomis marginatus	Dollar sunfish
	Lepomis microlophus	Redear sunfish
	Lepomis punctatus	Spotted sunfish
	Micropterus salmoides	Largemouth bass
	Pomoxis nigromaculatus	Black crappie
Centropomidae	*Centropomus undecimalis*	Snook
Cichilidae	*Aequidens portalegrensis*	Black acara
Clupeidae	*Dorosoma cepedianum*	Gizzard shad
	Dorosoma petenense	Threadfin shad
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner
	Notropis masculatus	Taillight shiner
	Notropis petersonii	Coastal shiner
Cyprinodontidae	*Cyprindon variegatus*	Sheepshead minnow
	Fundulus chrysotus	Golden topminnow
	Fundulus confluentis	Marsh killifish
	Fundulus notti	Starhead topminnow
	Fundulus seminolis	Seminole killifish
	Jordanella floridae	Flagfish
	Lucania goodei	Bluefin killifish
Elopidae	*Megalops atlantica*	Tarpon
Esocidae	*Esox americanus*	Redfin pickerel
	Esox niger	Chain pickerel
Ictaluridae	*Ictalurus catus*	White catfish
	Ictalurus natalis	Yellow bullhead
	Ictalurus nebulosus	Brown bullhead
	Ictalurus punctatus	Channel catfish
	Noturus gyrinus	Tadpole madtom
Lepisosteidae	*Lepisosteus osseus*	Longnose gar
	Lepisosteus platyrhincus	Florida gar
Poeciliidae	*Gambusia affinis*	Mosquito fish
	Heterandia formosa	Least killifish
	Poecilia latipinna	Sailfin molly
Percidae	*Etheostoma fusiforme*	Swamp darter

Source: Dineen, 1974

The Everglades fish community has adapted to a number of severe environmental conditions such as periodic drying of the marsh, high temperature extremes, low dissolved oxygen concentrations, and generally poor water quality experienced during low water periods. Native Everglades fish have developed physiological and behavioral adaptations to accommodate extremes in water level fluctuations and water quality (Dineen, 1974; Schomer and Drew, 1982). Several forage fish species are able to extract oxygen from the waters surface and are therefore not affected by periodic anaerobic conditions. Flagfish, mosquito fish and the sailfin molly (*Poecilia latipinna*) have been found to be extremely hardy species tolerant of very poor water quality conditions (Dineen, 1974). Many of these fishes have developed reproductive strategies which allow them to quickly reproduce and repopulate a newly flooded marsh.

Kushlan (1980 and 1976a) reports that the number and size-class distribution of fishes within the Everglades WCA study area is determined by the annual pattern of water level fluctuation. The seasonal water level variation results in a community dominated by small-bodied, omnivorous fishes with high reproductive potential. Kushlan (1976a) reports that when natural water-level fluctuations are stabilized, there is a shift in the community structure towards a population dominated by larger-bodied, carnivorous fishes, and predation replaces hydrology as the dominant factor influencing community structure.

An accumulation of organic flocculent (dead plant material), can build up as a result of vegetative production during periods of extended high water. This material interferes with fish spawning. Degradation of this material exerts a large biological oxygen demand which has been correlated with the occurrence of fish kills within the WCA-2A marsh (Dineen, 1972; Worth, 1988).

Generally, Everglades sport fish are harvested from the borrow canals which surround the marsh. As water levels in the canal and marsh rise, fish populations disperse into the interior marsh and reproduce with minimum competition and predation. As water levels recede, fish concentrate into the deeper waters of the surrounding canals where they become available as prey for wildlife and fishermen. In some instances, the canal fishery has experienced major fish kills due to overcrowding and oxygen depletion.

Studies conducted by the FGFWFC in WCA-2A during 1987 found the abundance and distribution of fish species within the interior marsh and perimeter canals to be quite different. Morello *et al.* (1988) sampled fish populations in the southern portion of the WCA-2A interior marsh and within the L-35B canal which separates WCA-2A from WCA-2B. In the marsh, total standing crop of fish was low averaging 24 pounds per acre, but density was extremely high averaging 24,000 fish per acre. Two small forage fish, the Florida flagfish and bluefin killifish accounted for 86 percent of the total fish density. Juvenile largemouth bass were collected in the marsh indicating successful reproduction for the second consecutive year. Higher minimum water levels implemented in 1986 improved spawning habitat for these fish. Between 1982 and 1987, fish standing crop in the marsh varied from 10 to 70 pounds per acre.

The L-35B Canal supported a higher standing crop but lower densities of fish as compared to the interior marsh. Total fish biomass and density in the canal averaged 347 pounds and 1,400 fish per acre, respectively. Sport fish comprised 64 percent of all fish collected. Since 1983, fish standing crop and density were highly variable and dependent on water level. When water levels were low in 1983 standing crop and density averaged 3500 pounds and 8,000 fish per acre, respectively. Similarly during the last five years, there was an negative relationship between water level and electroshocking catch-per-unit effort for density ($r = -0.96$) and weight ($r = -0.97$). Under drought conditions, fish become highly concentrated in WCA canals and at times the Florida Game and Fresh Water Fish Commission removed or greatly increased creel limits as low oxygen levels became critical to fish life (Morello *et al.*, 1988). Wiechman (1985) inventoried the fish population in WCA-1 and reported similar results regarding the response of Everglades fish communities to water levels.

The WCAs provide a valuable sport fishery to south Florida. In WCA-2A, 65 percent of the fisherman sought largemouth bass and 22 percent preferred to catch sunfish (Morello *et al.*, 1988). Success rates were high compared to other water bodies in Florida as catch-per-hour for largemouth bass, sunfish, and oscar was 0.66, 2.55, and 3.12 respectively in 1987-88. However, a 34 percent decline in angler use was noted between 1986-87 and 1987-88. During the six-month survey in 1987-88, largemouth bass anglers spent an estimated $265,000.

In WCA-3A, fish sampling in 1988 within the L-67A canal indicated that gar and bowfin (rough fish species) dominated the sample collection by weight (64%) (Morello *et al.*, 1988). Largemouth bass, sunfish, and catfish were also collected. Angler effort for largemouth bass was four times greater in WCA-3A compared to WCA-2A. However, success for largemouth bass, sunfish, and oscar were 0.26, 0.67, and 1.23 fish-per-hour, lower than that observed for WCA-2A.

Besides supporting a valuable recreational fishery for the region, WCA fish communities provide a major food source for Everglades wading birds, alligators, and other carnivorous reptiles and mammals. Fish community structure and abundance is highly dependent on water levels. Consequently, fishing success by humans or wildlife is also dependent on water levels (Dineen, 1974).

Mercury Contamination of Everglades Fishes. In February 1989, high levels of mercury (Hg) were found in the muscle tissue of largemouth bass inhabiting the WCAs. Health warnings were issued by the Florida Department of Health and Rehabilitative Service recommending reduced consumption of largemouth bass and warmouth from WCA-1 since they were found to contain mercury concentrations ranging from 0.5 to 1.5 mg/kg flesh.

In WCA-2 and WCA-3 mercury concentrations generally exceeded 1.5 mg/kg and consumption of largemouth bass and warmouth was not recommended. Warmouth are a popular pan fish species that also prey on smaller fish and thus have the potential for the possible biomagnification of mercury. Mercury testing of fish collected from the EAA canals, Lake Okeechobee and waters which flow into the WCAs, indicated that largemouth bass were safe to consume. Largemouth bass displayed higher levels of mercury, while lower trophic level fish such as bluegill (*Lepomis macrochirus*) and redear sunfish (*Lepomis microlophus*) contained lower mercury concentrations. Bioaccumulation was evident in largemouth bass as generally larger fish demonstrated higher mercury concentrations. At this time, the cause of elevated mercury levels in largemouth bass inhabiting the WCAs is not known. The Water Quality Division of the SFWMD has initiated a sampling program to determine mercury levels in the soil and canal sediments throughout the region. This program, being carried out in cooperation with DER and HRS, may provide information on the source and causes of mercury contamination in largemouth bass.

Reptiles and Amphibians. The American Alligator, more than any other species, is most often identified with the Everglades and it's unique wetland ecosystem. The alligator has made an impressive comeback in terms of population numbers since the 1960s when the reptile was placed on the endangered species list by the USFWS. Today, alligator populations in the WCAs and throughout Florida have increased in sufficient numbers to support a controlled harvest program (FGFWFC, 1986).

Alligators have been cited to serve an important ecological function by maintaining "gator holes", or depressions in the muck, which are thought to provide a refuge for aquatic organisms and constitute a concentrated food source for wading birds and other Everglades predators during drought (Kushlan, 1974, 1976a). The validity of this concept is currently being questioned.

Water levels represent the important factor influencing alligator in the WCAs. nesting success of alligators in the WCAs (Ault, pers. com., 1989). High water levels during the period of nest construction, which occurs from June to early July (Woodward *et al.,* 1989), decreases the availability of nesting sites, which in turn results in decreased nesting efforts (Joanen and McNease, 1979). Optimum nesting effort and success is observed when water levels remain stable or decrease throughout the nesting season (June - September). Significant nest loses, due to increasing water levels during the nesting season, have been reported by several workers (Joanen, 1969; Jacobsen and Kushlan, 1986; Hines *et al.,* 1968). Joanen *et al.* (1977) reported total submergence of eggs for 48 hours resulted in mortality.

Low water levels during the spring have been associated with decreased nesting (Joanen and McNease, 1972a, b, c; Palmisano *et al.,* 1973; Schemnitz, 1972). Aerial nest surveys were conducted in WCA-2 and WCA-3 in 1988 and 1989 (L.J. Hord, Feb. 8, 1990, FGFWFC comments on Nov. 8, 1989 SWIM Plan). Three hundred and fifty nests were observed in 1988 and 75 in 1989. The WCAs experienced low water levels in the spring of 1989. A water management scheme that promotes maximum habitat and species diversity, while maintaining adequate water levels in the spring, and minimizes water levels increases from June through September, would be most beneficial to alligator nesting success (FGFWFC comments on Nov. 8, 1989 Everglades SWIM plan, see Appendix E).

The current alligator management program is designed to conserve alligators and their habitat throughout the state by establishing mechanisms which will provide economic incentives to public and private interests who, as direct benefactors of the resource, will develop a vested interest in maintaining these wetlands in their natural condition (FGFWFC, 1986). The current program includes collection of eggs and hatchlings for captive rearing as well as traditional hunting of adult alligators for hides and meat. The average gross market value for adult alligators (hides and meat) is estimated at $430.00 (Jennings *et al.,* 1989). The license fee for each egg collected is $5.00. The tag fee for each hatchling collected is $15.00. Under the current tag and license fee schedule, anticipated revenues based on 1988 nesting levels, to the state in tag and license fees was $17,500 Anticipated revenues to the state for the 1989 adult harvest were $26,070. The projected gross value to hunters for the 1989 adult harvest was $251,550 (L.J. Hord, Feb. 8, 1990, FGFWFC comments on Nov. 8, 1989 SWIM Plan). Due to a concern over the high concentrations of mercury found in the flesh of alligators and Everglades fish, the scheduled 1989 hunt in the WCAs was called off by the FGFWFC until more information becomes available concerning the public health aspects of the consumption of alligator meat obtained from the WCAs. In addition, no harvest of eggs or hatchlings occurred in the WCAs in 1989 due to the low level of nesting (FGFWFC comments on Nov. 8, 1989 Everglades SWIM plan, see Appendix E).

Other important reptile species commonly encountered within the Everglades WCAs includes turtles, lizards, and snakes. Turtles include the snapping turtle (*Chelydra serpentina*), striped mud turtle (*Kinosternon bauri*), mud turtle (*K. subruburm*), cooter (*Chrysemys floridana*), Florida chicken turtle (*Deirochelys* *reticularia*), and Florida softshell turtle (*Trionys ferox*). Lizards such as the green anole (*Anolis carolinensis*), are found in all the WCAs and several species of skinks, occur more commonly in terrestrial habitats. Numerous snakes inhabit the WCAs. Drier habitats support such species as the Florida brown snake (*Storeria dekayi*), southern ringneck snake (*Diadophis punctatus*), southern black racer (*Coluber constrictor*), scarlet snake (*Cemophora coccinea*), and two rattlesnakes (*Sistrurus miliarius and Crotalus adamanteus*). The eastern indigo snake (*Drymarchon corais*), a federally listed endangered species, and the Florida pine snake (*Pituophis melanoleucus mugitus*), a state Species of Special Concern, may also exist in drier areas of the study area. Wetter habitats support more aquatic species such as the water snake (*Natrix sipedon*), the green water snake (N. *cyclopion*), mud snake (*Francia abacura*), eastern garter snake (*Thamnophis sirtalis*), ribbon snake (*T. sauritus*), rat snake (*Elaphe obsoleta*), and the Florida cottonmouth (*Agkistrodon piscivorus*) (McDiarmid and Pritchard, 1978).

Important amphibians that are characteristic of the WCAs include the Everglades bullfrog, or pig frog (*Rana grylio*), which occurs primarily within wet prairie and aquatic slough habitats throughout the Everglades (Ligas, 1960). This amphibian is considered an important economic species and provides recreation for sportsmen and some supplemental income for a few commercial froggers who market these animals through wholesalers, hotels and restaurants. The life history and ecology of this species have been reviewed by Ligas (1960). Other important frog species include the Florida cricket frog (*Acris gryllus*) and southern leopard frog (*Rana sphenocephala*) are common in marshes and wet prairies, while such species as the southern chorus frog (*Pseudacris nigrita*) and various tree frogs (squirrel tree frog, *Hyla squirela;* green tree frog, *H. cinerea*) are common to tree islands and cypress forests. Salamanders inhabit the densely vegetated, still or slow-moving waters of the sawgrass marshes and wet prairies. They include the greater siren (*Siren lancertina*) and the Everglades dwarf siren (*Pseudobranchus striatus*). Toads such the eastern narrow-mouth toad (*Gastrophryne carolinensis*) also occur within the study area.

Avifauna.

Wading Birds. Colonial wading birds (Order Ciconiformes) are a conspicuous component of the wildlife communities which utilize the WCAs as both feeding and breeding habitat. These include 11 species of herons and egrets, two species of ibis, the wood stork, and the roseate spoonbill (Robertson and Kushlan, 1984). Historically, white ibis (*Eudocimus albus*) has been the most abundant colonial wading bird species within the Everglades WCA study area. Recent surveys indicate that the great egret (*Casmerodius albus*) is the second most abundant species (Frederick and Collopy, 1988). The great blue heron (*Ardea herodias*), little blue heron (*Egretta caerulea*), tricolored heron (*E. tricolor*), green-backed heron (*Butorides striatus*), snowy egret (*E. thula*), cattle egret (*Bubulcus ibis*), black-crowned night heron (*Nycticorax nycticorax*), and yellow-crowned night heron (*N. violacea*), are also common wading bird species found throughout the WCAs. The roseate spoonbill (*Ajaia ajaja*), a state species of special concern, and the wood stork (*Mycteria americana*), a federally listed endangered species, both occur within the study area.

Most Everglades wading bird species exhibit a seasonal pattern of abundance, being more abundant during the dry season than during the wet season. The majority of species nest in late winter or early spring, although a few, such as the great egret, are reported to nest at different times throughout the year (Kushlan and

White, 1977a). The WCAs support additional aquatic avifauna, such as the limpkin *(Aramus guarauna)*, two bitterns *(Ixobrycus exilis* and *Botarus lentiginosus)*, the anhinga *(Anhinga anhinga)* as well as a number of resident and migratory waterfowl (discussed below).

The reproductive cycle of most Everglades wading birds is tightly linked with seasonal water level fluctuations within the marsh. During the rainy season, when water levels are high, fish and invertebrate prey species repopulate the newly flooded marsh and begin to increase in abundance. As water levels recede during the dry season, the density of these prey species (topminnows, mosquitofish, killifish, crayfish, freshwater prawns and insect larvae) increase as they concentrate in remnant pools and along the edge of the drying marsh. Concentration of aquatic prey species during the dry season provides an easily harvested food source for wading birds. It has been estimated that the standing stock of fish increases from about 50 kilograms per hectare to about 500 kilograms per hectare between the rainy season and the dry season (Kushlan *et al.*, undated). Concentration of these food resources has been shown to be a major factor in the initiation of nesting for the wood stork (Kahl, 1964) as well as for other wading bird species.

Population Declines. Loss of habitat and man-induced changes in the natural hydrologic cycle (i.e. distribution of historical water flows and the timing of seasonal drying of the marsh) are thought to represent the major factors affecting the decline of colonial wading bird species in South Florida. Historically, the Everglades WCAs supported large numbers of wintering and breeding wading birds (Robertson and Kushlan, 1974). South Florida wading bird populations have suffered two major declines in this century. Plume hunting at the turn of the century nearly wiped out several species. Most scientists agree that federal protection measures enacted in 1910 allowed wading bird populations to rebuild to healthy levels by the 1930's (Allen, 1964; Robertson and Kushlan, 1974; Ogden, 1978; Kushlan and Frohring, 1986; Frederick and Collopy, 1988). Sometime in between the late-1940's and the mid-1960's, numbers of breeding wood storks, tricolored herons, snowy egrets and white ibis declined several orders of magnitude (Kushlan and White, 1977a; Ogden, 1978; Kushlan *et al.*, 1984; Kushlan and Frohring, 1986; Frederick and Collopy, 1988). Kushlan and Frohring (1986) suggest that the decline of the wood stork population coincided with changes in the regional water management system initiated in the 1960's, rather than the gradual declines observed since the 1940's (Sprunt and Kahl, 1960). Although the extent of the population decline is a subject of controversy, much of it has occurred since construction of the regional water management system largely completed in 1962. The physical compartmentalization of the Everglades by levees and canals has caused major changes to historical flow patterns, water depths, the natural timing of water level fluctuations and the distribution of water within the WCAs and ENP (Kushlan, 1987). Water depths in some areas of the system are now much deeper than they were historically, while other areas of the system are substantially drier. Under both conditions, the natural timing of these water level fluctuations has been altered (Kushlan, 1987). Implementation of the minimum delivery schedule (1967) for delivery of water to ENP and the addition of the L-67 extension canal and associated levee has exacerbated these timing and delivery problems and is thought to be directly related to the poor nesting success of wood storks within ENP (John C. Ogden, 1989, South Florida Research Center, ENP, pers. com.).

Loss of wading bird habitat due to the conversion of seasonal wetlands to agriculture has also been cited as an important factor. Browder (1976) reported that wading bird feeding habitat south of Lake Okeechobee has been reduced by 35 percent since the turn of the century resulting from the conversion of sawgrass wetlands to sugarcane farming. It is generally believed that the combined effects of habitat destruction, loss of feeding areas, and disruption of historical hydroperiod patterns represent the primary factors affecting the decline of wading bird populations in south Florida.

Wading Bird Requirements: The majority of wading bird species require shallow water depth for efficient feeding. White ibis rarely forage in waters deeper than 15 cm while almost all of the smaller heron species are too short to wade in waters deeper than 20 cm (Custer and Osborne, 1978; Kushlan, 1974). Construction of water management canals and levees have rendered many areas of the WCAs as unsuitable wading bird feeding habitat due to the ponded, deep water conditions which prevail in these areas.

Regardless of whether a wading bird is a tactile or sight feeder, all species rely heavily on receding water levels during the dry season and the associated concentration of prey species (crustaceans and fish) for optimum reproductive success. The mechanical concentration of prey species produced by the natural drying of these wetlands is essential for the nesting success of such tactile feeders as the wood stork and white ibis (Kahl, 1964; Kushlan, 1974; Kushlan, 1976a; Frederick and Collopy, 1988). The wood stork is considered to be highly sensitive to seasonal water-level fluctuations. Successful nesting requires that a concentration of fish be present within a certain distance of its nesting colony for the entire length of its nesting period (Kahl, 1964). Nesting may not be initiated if there is insufficient concentration of fish due to poor fish production during the rainy season, or due to high water levels during the dry season. Similarly, nest failure is likely if water levels rise before the end of the nesting period. Of all colonial wading birds, the wood stork exhibits the most dramatic response to water-level changes. The nesting success of wood storks parallel many other colonial wading bird populations, and as a group are considered a good indicator of the effects of water-level changes on colonial wading bird populations in the Everglades. Poor feeding conditions and poor nesting success result from changes in the natural hydrologic cycle (i.e. timing of the seasonal drying of the marsh). Increased or rising water levels during the nesting season cause wood storks, white Ibis and small herons to abandon their nests (Frederick and Collopy, 1988). Slow drying or interrupted drying rates, or late drying of the marsh relative to the normal nesting period all contribute to poor reproductive success of colonial wading birds (Frederick and Collopy, 1988). Stabilized water levels, extended hydroperiods or long term, deep water conditions provide poor foraging habitat for the majority of Everglades wading birds. The duration of optimal feeding conditions is also an important factor in wading bird nesting success. Prime feeding conditions must be available during the entire nesting period to achieve maximum reproductive success. Optimum conditions for successful breeding would be a long, protracted drying of the marsh that would encompass the entire breeding cycle (nesting and providing forage for fledgling and juvenile birds (Frederick and Collopy, 1988).

Wading Bird Diet and Prey Preferences. White ibis, the most abundant wading bird found in the WCAs, feeds primarily on crayfish (*Procambarus alleni*) comprising about 66 percent of its diet by energy content with invertebrates comprising 25 percent (Kushlan and Kushlan, 1975). In contrast, wood storks feed almost exclusively on fish (Ogden *et al.,* 1976). Although both species are tactile foragers, differences in prey preference and foraging strategies allow both species to utilize drying wetlands with minimum competition. The diet of sight feeding wading birds (herons and egrets) generally includes forage fish (topminnows, killifish and mosquitofish), small reptiles (snakes and lizards) and frogs, crustaceans (crayfish, fresh water prawns), snails and insect larvae.

Current status of Wading Bird populations in WCAs. Recent (1987-1988) aerial surveys (Systematic Reconnaissance Surveys or SRF flights) were conducted to determine the foraging habitat requirements and map the movement of colonial wading birds (herons, egrets, wood storks and ibis) within WCA-1, WCA-2A, WCA-2B, WCA-3A (Hoffman *et al.*, 1989). Results of these surveys indicated that White ibis, great egrets, great blue herons, wood storks, little blue herons, snowy egrets cattle egrets, glossy ibis and an occasional roseate spoonbill are the most common wading bird species utilizing the WCAs with populations varying widely in relationship to seasonal water level fluctuations. Peak wading bird use of the WCAs occurred in January in relationship to receding water levels with over 121,000 birds observed. A second smaller peak was recorded in March. Lowest counts occurred during August with less than 15,000 birds counted. White ibis represented the most abundant wading bird observed with total counts ranging from 894 (August) to 88,621 (January) birds during 1987-1988, and moved in and out of the WCAs in response to changing water levels. Great egrets represented the second most abundant group of wading birds observed.

Population estimates showed two residency patterns. Great blue herons and great egrets are residents in the WCAs during the dry season with consistent population sizes during this period. White ibis, wood storks and small white and dark herons fluctuate in numbers in response to rising and falling water levels. Peak populations occur during the winter months (often during March) with numbers declining in the spring. These birds leave the WCAs during the wet season. The WCAs provide an important staging habitat for ibis, wood storks, small white and dark herons prior to their migration to the north.(Hoffman *et al.*, 1989).

Snail Kite. Another species of Everglades avifauna that is directly dependent on hydrologic conditions within the WCAs is the [Everglade] snail kite. The snail kite is a medium-sized raptor of the Neotropics. Although common in South and Central America, Mexico and Cuba, the Florida snail kite *(Rostrhamus sociabilis plumbeus)* is listed as an endangered species by the federal government and the state of Florida. The snail kite is an obligate wetland species that requires flooded wetland areas to produce its primary food source, the apple snail *(Pomacea paludosa)*. The snail kite has developed a curved, sharp-tipped bill that is specially adapted for extracting snails of a single genus, *Pomacea*, from their shell (Kale, 1978).

Many wildlife experts consider the snail kite and the wood stork as good barometers of the Everglades ecosystem. When both species are maintaining healthy populations it generally signifies that the system is working close to historic conditions. However it should be noted that the snail kite is considered a "boom or bust" species, that is, populations historically increase during wet years and dramatically decline as a result of drought.

Although snail kites were historically observed in WCA-1 and WCA-2A, the majority of South Florida's kite population is found today in the central and southern portion of WCA-3A. In 1983, 92 percent of Florida's snail kite population in Florida occurred in WCA-3A (Bennetts *et al.*, 1988). The south end of WCA-3A has been the major nesting and foraging area for kites for the past 15 years and has received designation as "critical habitat" by the USFWS (Bennetts *et al.*, 1988). The snail kite population in WCA-3A fluctuates annually. The reported snail kite population in WCA-3A for 1983 reflects a period of high use. Survey data from 1980 through 1989 indicates approximately 60 percent of Florida's snail kite population occurred in WCA-3A (J. A. Rodgers, Jr. FGFWFC, personal communication) In recent years, WCA-2B has also been utilized by snail kites.

There is concern that the recent drought has had a significant impact on the resident snail kite population in WCA-3A. A recent survey of the area indicated zero nesting success during the 1988-1989 breeding season due to the 10-month drought. Surviving birds migrated north to the lakes and marshes of central Florida. Wildlife experts anticipate that the population may drop from 500 to 300 birds by the December 1989 annual count.

Florida's snail kite population experienced steady declines during the early 1900s resulting from the construction of major drainage and flood control projects initiated in the northern Everglades. Over-drainage of these wetlands is thought to have reduced the production of apple snails by destroying or modifying the hydrologic regime of the original marsh. Lowest population levels of snail kites occurred from 1950-1965 with perhaps fewer than 40 individual birds remaining (Sykes, 1983). From 1965-1980, snail kite populations increased 803 percent with a population of 651 birds reported in a 1980 census (Sykes, 1983). Since 1969, much of the population has shifted from WCA-1 and WCA-2A to the south end of WCA-3A. Snail kite abundance has also increased in WCA-2B and WCA-3B. Lake Okeechobee and WCA-3A currently harbor the largest number of birds and nesting sites in south Florida.

Snail kite recruitment is directly linked to depth and duration of water levels within the Everglades, which in turn regulate the abundance of apple snails (Sykes, 1983; Bennetts *et al.*, 1988). Optimum hydrologic conditions for successful snail kite nesting (and apple snail production) exist in water depths ranging from 20 to 80 cm with seasonal drying intervals of no less than 0.8 years (305 days) and no longer than four to five years (Bennetts *et al.*, 1988). Complete drying of the marsh for extended periods of time results in low or zero nesting success with occasional mortality of adult birds observed. During drought, some portions of the population disperse to other parts of the state to find acceptable foraging habitat (Beissinger and Takekawa, 1983).

Impoundment by levees and canals caused water to pool in the southern portion of WCA-3A resulting in a lengthened hydroperiod north of Tamiami Trail (U.S. 41). Although this condition was not anticipated as part of the design of the C&SF project, stabilized water levels increased the amount of aquatic slough vegetation present in the south end of WCA-3A, creating optimum conditions for the production of apple snails. The optimum range of snail kite nesting relative to ground level elevations in WCA-3A occurred between 2.1 M (6.8 ft.) and 2.5 M (8.2 ft.) during 1986-1987 as shown in **Figure 17** (Bennetts *et al.*, 1988). Creation of favorable snail kite habitat in the south end of WCA-3A is thought to be responsible for an observed shift in the snail kite population into WCA-3 (Sykes, 1983; Bennetts *et al.*, 1988).

The snail kite prefers open-water slough and wet prairie (*Eleocharis* sp. flats) habitats with long lines-of-sight for foraging. Dense vegetation provides relatively poor snail kite habitat. In WCA-3A kites prefer to build their nests in short, woody vegetation, (e.g. willow trees) over open water to reduce predation of the kite's nest (Sykes, 1983). Dry hammocks or tree islands are avoided due to increased predation. Snail Kites rarely build nests over water shallower than 20 cm (Bennetts *et al.*, 1988).

Mammals.

WCA Deer herd. White-tailed deer (*Odocoileus virginianus*) have lived in the Everglades for centuries, long before the marsh was impounded by a system of levees and water control structures. Information collected in recent years indicates that Everglades deer herds fluctuate widely in response to flood and drought cycles. However, little information is available which identifies what the original carrying capacity was of the system prior to construction of the present day water management system. In the past, deer populations were generally described as a "boom or bust" proposition, increasing during an extended dry period, and decreasing during prolonged wet periods, depending on water levels. (FGFWFC, 1983).

During high water periods, deer concentrate on tree islands and levees and spoil banks causing competition for available forage and resting areas, increase the transmission of diseases and parasites, as well as causing physical and behavioral stress to these animals. If high water levels persist, the food supply becomes exhausted, malnutrition develops resulting in a large scale die-off of the herd.

Newly born fawns and crippled or diseased animals are usually the most susceptible individuals within the population. Highest fawning activity occurs in February. If high water levels are experienced during this critical time, then fawn mortality is high. Regression analysis shows a strong negative correlation ($r = 0.7$) between herd recruitment and marsh water levels. High recruitment is experienced during low water, while low recruitment is typical during high water periods (Discussion April, 1989 with John Ault, FGFWFC).

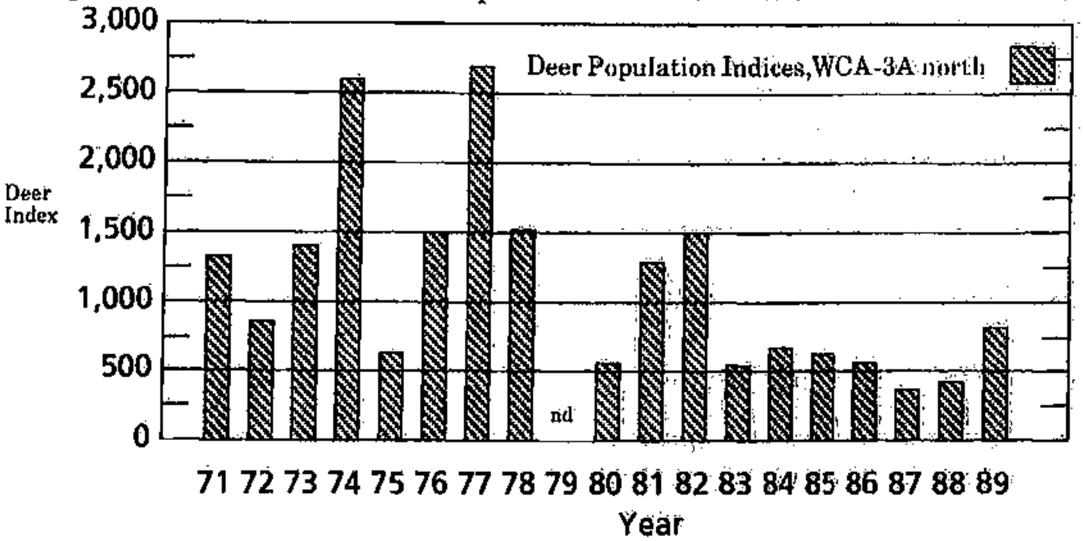
The FGFWFC manages essentially four separate deer herds within the WCAs. These are identified as WCA-2A and 2B (managed as one unit), WCA-3A north, WCA-3A south, and WCA-3B. Assessment of these four areas in 1987 indicated that the WCA deer herd is currently healthy and in good condition based on analysis of percent kidney fat, counts of liver fluke and stomach parasites (Ault, 1989).

Figure 26 presents a summary of deer population indices in WCA-3A north (north of Alligator Alley). Prior to 1979, the deer population fluctuated widely from year to year with higher numbers of animals maintained in the area as compared to levels maintained since 1982. In 1979 and 1982, two highly publicized water-related die-offs occurred in WCA-3A. The die-off in 1982 required a controversial Special Emergency Deer Hunt (July, 1982) to protect the remaining herd and minimize the extent of deer mortality (FGFWFC, 1983).

Since 1982, the Commission's policy has been to maintain deer herd size at a carrying capacity that will prevent the large scale die-off experienced in 1982 resulting from prolonged high water levels. The strategy developed to meet this objective was to establish an index (Norton-Griffins index) of the deer population that could survive prolonged high water conditions with having little effect on the overall health of the herd, while keeping the adult sex ratio between 1:2 and 1:3. The population index objectives for each of the four deer management areas located within the WCAs are currently 1,000 for WCA-3A north, 1,500 for WCA-3A south, 500 for WCA-3B and 250 for WCA-2A and 2B (Discussion April 1989 with John Ault, FGFWFC).

Since 1983, the FGFWFC has collected data and tested management practices demonstrating that it is possible to control both herd size and adult sex ratios. From 1983 to 1986, the primary short-term objective was to control the sex ratio and herd

Figure 26. Mean Deer Herd Population Indices for WCA-3A North 1971-1989.



Source: (Data provided by John Ault, FGFWFC, April, 1989) nd = no data

size. This was achieved by regulating the doe harvest. However, because of this emphasis, herd size remained below the FGFWFC population objectives. In 1987, the Commission initiated a number of management practices designed to allow for an increase in herd size up to the objective. Justification for these actions were based on the following: (1) Only a small die-off resulted from the high water events recorded in the summer of 1986; (2) Herd size was below FGFWFC objectives for each management zone; (3) Sex ratios were at desired levels with the FGFWFC demonstrating their ability to regain control of the population if ratios become skewed; and (4) Increased herd size provides more hunting opportunities.

In 1987, the primary management action taken to increase herd size up to the carrying capacity of these wetlands was to reduce the number of doe tags issued by 83 percent. This strategy however, has not yet produced the desired result with 1987 and 1988 experiencing below average recruitment. Low recruitment may also be related to the time lag required for herd composition changes to show up in older age class individuals. For 1989, the Commission recommends (a) continuing the restricted doe harvest; and (b) recommending moderate hunting pressure on the buck population to increase recruitment levels (Ault, 1989, personal communication).

5. Water Quality Characteristics.

Prior to drainage and development of the Everglades, this vast sawgrass wetland functioned essentially as a nutrient-limited ecosystem with phosphorus and inorganic nitrogen concentrations at extremely low levels. The majority of nutrients are presumed to have been derived from direct rainfall (Davis, 1943a; Parker, 1974; Waller and Earle, 1975; McPherson *et al.*, 1976; Davis *et al.*, 1987). Data collected in recent years show that a number of water quality changes have taken place within the northern Everglades WCAs and that many areas of the marsh are now subjected to elevated nutrient concentrations which have impacted native plant communities and marsh ecosystem structure and function (LOTAC-II, 1988; Swift and Nicholas, 1987; Davis, 1989, 1991). The increased nutrient load is derived primarily from drainage of agricultural lands located within the EAA and to a lesser extent, urban lands located to the east (LOTAC-II, 1988).

Since drainage systems were constructed within the EAA, surface water runoff from this agricultural region has historically contained high concentrations of nitrogen and phosphorus resulting from soil subsidence (the biological oxidation of nitrogen-rich organic peat soils) and the use of phosphorus as fertilizer. EAA drainage waters also contain high concentrations of dissolved minerals (chlorides, sodium, and calcium carbonate) and trace metals (copper, zinc, lead and iron) as compared to interior marsh sites unaffected by agricultural surface water runoff (Lutz, 1977a, b; Dickson *et al.*, 1978; CH_2M-Hill, 1978). Pesticides are also found as a contaminant of EAA drainage water (Kolpinsky and Higer, 1969; Waller and Earle, 1975; Milleson, 1980; Pfeuffer, in press). Trace amounts of pesticide and herbicide residues (atrazine and zinc phosphide) are occasionally found in Everglades surface waters and sediments near water management inflow structures (Pfeuffer, in press). Increased nutrient loadings in combination with hydroperiod changes and the effects of fire have produced adverse impacts to native Everglades marsh vegetation within all three WCAs and are considered a threat to the biological integrity of the ecosystem (LOTAC-II, 1988). Areas of the marsh that appear to be most affected are sites that are located downstream of water management inflow structures. The majority of these water management structures were built over 30 years ago as part of the C&SF Project to provide flood control, water supply and other benefits to the region.

In addition to the nutrient loading problem, recent evidence indicates that the heavy metal, mercury, is currently contaminating the flesh of fish and reptiles harvested from WCA and ENP canals (HRS, 1989). Long-term consumption of mercury-contaminated fish could potentially cause mercury toxicity in humans, especially children and expectant mothers. A public health advisory is in effect, urging limited consumption of largemouth bass, warmouth and alligator meat obtained from portions of the WCAs and ENP canal systems. At this writing, the source of mercury contamination in Everglades surface waters is not well understood. An inter-agency investigation of the problem is currently underway within the study area.

Previous Water Quality Studies Conducted within the WCAs: The U.S. Geological Survey (1941-1945) initiated the first investigations concerning the surface water quality of WCA canals and ground water (Parker *et al.*, 1955). Parker's investigations of the Hillsboro and North New River canals found them to be highly mineralized with respect to dissolved solids, bicarbonate, chloride, sodium and specific conductivity. Nitrate concentrations ranged from 0 - 2.4 mg/l.

These early investigations were not followed up until the 1970s when the USGS organized the first comprehensive studies of water quality within the Everglades (Freiberger, 1972, 1973; McPherson, 1973; Mattraw, 1973; McPherson *et al.*, 1976; Miller, 1975; Waller, 1975; Waller and Earle, 1975). Results of these studies found concentrations of dissolved minerals, nutrients and pesticides (chlorinated hydrocarbons) to be higher within the northern areas of the Everglades influenced by agricultural development as compared to undeveloped wetlands located within the Water Conservation Areas, the Big Cypress or Everglades National Park.

McPherson (1973) initiated water quality investigations in the WCAs from 1970 to 1972 in cooperation with the USGS and SFWMD (then known as the Central and Southern Florida Flood Control District). Results of this study indicated that waters draining agricultural lands to the north of the WCAs was of poor quality and contained high concentrations of dissolved solids, nutrients and pesticides (breakdown products of DDT) impacting the north and northeast portions of the WCAs. Dissolved solids were highest in the north and northeast portions of the WCAs where averages ranged from 471 to 641 mg/l, and lowest in the south (WCA-3A) where averages ranged from 172 to 387 mg/l. McPherson (1973) attributed these high dissolved solids concentrations to the combined effects of groundwater and the proximity of WCA-1 to agriculture "During low-water periods, a relatively large part of canal water comes from the groundwater contributions. Ground water is more saline in the northern Everglades than in the southern part [citing Parker and others, 1955]. During high-water periods, agricultural land is drained by pumps which discharge water with high dissolved solids into canals in the northern Everglades".

Pesticides (primarily the break down products of DDT) showed a similar trend. DDT residues in canal bottom sediments averaged 192 ug/kg in the northern WCAs as compared to 13.8 ug/L in the south. DDT levels averaged 723 ug/kg within centrarchid fish collected from the north end of WCA-1, 264 ug/kg at the south end of WCA-1, 230 ug/kg in WCA-2A and 56 ug/kg in WCA-3A. Dieldrin and toxaphene were also found in high concentrations from fish collected within WCA-1 and WCA-2A canals, while polychlorinated biphenyls (PCBs) were highest in sediment samples collected from WCA-2A. Trace metal concentrations exceeded state water quality criteria at the S-10 structures located between WCA-1 and WCA-2A, and in the Miami Canal located in WCA-3A. Seasonal drying of the Everglades also affected canal water quality. The highest concentrations of nutrients were observed following the 1971 drought.

Several investigations (Freiberger, 1973; Mattraw, 1973; McPherson *et al.*, 1976) focused on evaluating the quality of water being discharged into the WCAs as a result of the water management practice of "backpumping" (pumping water against gravity into Lake Okeechobee or the WCAs for flood control or water supply purposes). These studies indicated that water quality had changed within certain regions of the Everglades and that increased concentrations of nutrients from agriculture and urban development had influenced water quality at various locations.

Mattraw (1973) examined the effects of pumping nutrient-enriched water into the north end of WCA-1 at pump station S-5A. Results showed that specific conductivity and nutrient concentrations were low at interior marsh sites and high at perimeter canal sites, indicating that interior marsh sites appeared relatively unaffected by pumping in the areas sampled. Dissolved oxygen concentrations were shown to decrease while ammonium concentrations increased during pumping events due to the resuspension of bottom sediments and associated increased biological oxygen demand. Similar results were shown at pump station S-9 located in WCA-3A (Freiberger, 1973). Pumping produced short-term impacts including decreased dissolved oxygen concentrations and increased ammonium levels. These changes were observed three miles downstream from the S-9 pump station.

McPherson *et al.* (1976) published similar results indicating that water pumped into the northern WCAs was high in both dissolved minerals and nutrients. Nitrogen and phosphorus were rapidly assimilated by marsh vegetation and sediments within a short distance from perimeter canals. Canals in the northern and eastern portions of the WCAs experienced low dissolved oxygen concentrations and increased nutrient concentrations (primarily ammonia) immediately following pumping events. The study expressed concerns that increased nutrient loading could potentially change the Everglades environment by causing increased growth of aquatic plants, shifts in food web structure, and possibly effects on wildlife populations.

Klein *et al.* (1975) reported that Everglades surface water quality had changed in areas of the marsh subjected to inflows from drainage areas outside the WCAs. Dissolved solids and chloride had increased in waters originating from, or passing through the EAA. Water backpumped to the WCAs from urban and agricultural areas had also changed water quality within certain areas of the Everglades marsh. In Everglades National Park (ENP), chloride concentrations at station P-33, located in Shark River Slough, had increased from 10 to 70 mg/l since 1959. The study predicted that water control within the EAA will most probably affect water quality within other areas of the Everglades region in the future. Water draining the EAA and east coast urban areas was of poor quality. Urban and residential development within these areas are likely to increase rather than decrease in the future. A study of pesticides at ten sites within the WCAs showed that concentrations of DDT were low in surface waters collected from agricultural lands and at marshes sites remote from agriculture. Sediment and fish samples indicated that DDT concentrations were higher near sites influenced by agricultural activities.

Waller and Earle (1975) reported similar results, showing generally poor quality water being discharged into the WCAs from the EAA at major inflow points. Results showed that the quality of water within the EAA was markedly different from other surface waters in southeastern Florida. Agriculture and urban development had affected water quality in the northern and eastern portions of the Everglades study area. Water entering ENP was of better quality than that entering the northern WCAs. Highest concentrations of major ions (bicarbonate, chloride, sodium) and highest specific conductivity values were recorded within EAA canals, the perimeter canals of WCA-1, WCA-2A canals and marsh, and the northern portion of WCA-3A. These high values were thought to be the result of canal waters mixing with mineralized ground water which had come in contact with connate sea water present in ancient marine sediments which underlie the organic soils of the EAA and northern WCAs (see also Parker *et al.,* 1955). Much of this highly mineralized water is pumped south into WCA canals. Median total phosphorus concentrations were highest in the northeastern (pump stations S-5A and S-6) and northwest portions of the Everglades study area. Waller and Earle (1975) attributed high phosphorus levels recorded in EAA canals and the northeastern portion of the WCAs to agricultural activities within the EAA, while underlying clay sediments containing high phosphorus concentrations were thought to be responsible for the high phosphorus values recorded in the northwestern portion of the study area. Highest nutrient concentrations in the WCAs canal system occurred during the wet season, while interior marsh sites experienced highest concentrations during the dry season. Average trace metal concentrations were below state water quality standards for Class III waters. High iron concentrations, typical of the organic soils within the study area, exceeded the criteria on some occasions, while chromium was found to exceed the criteria once. The pesticides most frequently encountered within WCA drainage waters were parathion and chlordane with diazinon, dieldrin, methyl parathion and DDE occurring infrequently. Concentrations of DDT residues in canal bottom sediments were generally higher within the EAA as compared to other areas of the Everglades. The authors suggest that the Everglades functions as a sink for macronutrients, trace metals and chlorinated-hydrocarbon insecticides. These pollutants are tied up in various complexes (sediments and marsh vegetation), and for that reason, water delivered to ENP is of better quality than water that enters the WCAs.

Rainfall (bulk precipitation) appeared to be the major contributor of inorganic macronutrients (ammonia, nitrate, nitrite and orthophosphorus) to Everglades surface waters. Average total phosphorus concentration for bulk rainfall in WCA-3A and ENP, excluding samples contaminated by organisms, was 0.032 mg/l (Waller and Earle, 1975, Tables 13 and 14). Bulk precipitation is probably the major contributor of nitrogen and phosphorus to the Everglades ecosystem (Waller and Earle, 1975). Waller (1975) estimated that bulk precipitation was the primary source of nutrients for the WCAs representing about 78% of the nitrogen and phosphorus inflow. A materials budget analysis indicated that as a whole, the WCAs retained about 74% (5,500 tons) of nitrogen, and 96% of the phosphorus (242 tons) discharged into the study area during 1972-1973 (Waller, 1975).

The potential for utilization of the Everglades marsh for waste water treatment was assessed in a study by the U.S. Department of Agriculture (Steward and Ornes, 1975b) within WCA-3B. Nutrients were applied to confined stands of sawgrass with estimates of nutrient uptake and growth response obtained, as well as nutrient distribution and movement. Within 12 weeks, the native periphyton-bladderwort (*Utricularia* spp) algae mat had disappeared being replaced by dense phytoplankton blooms for the duration of the study due to continuous, weekly applications of phosphorus. Plant community composition was altered, indicating that changes in vegetation would occur if the supply of nutrients to the Everglades ecosystem was increased. Results of the study indicated that the sawgrass marsh has low nutrient requirements and therefore has a limited capacity for assimilating nutrients (waste water) introduced into the system.

Results of these initial studies sponsored by federal agencies brought into focus the need for the SFWMD to develop a more comprehensive data base concerning the quality of water discharged through District water control structures into the WCAs and Lake Okeechobee. As a result, the District initiated a number of water quality investigations within the study area during the 1970s and early 1980s (Gleason, 1974a; Lutz, 1977a, 1977b; Dickson *et al.*, 1978; Millar, 1981; SFWMD, 1987). These studies were augmented by a variety of biological studies designed to assess the impacts of agricultural runoff on Everglades water quality and native plant communities (Gleason *et al.*, 1974c; Davis and Harris, 1978; Swift, 1981; Davis, 1982, 1984; Reeder and Davis, 1983, Swift, 1981; Swift and Nicholas, 1987; Belanger and Platko, 1986).

Gleason (1974b) conducted the first detailed study of water quality within the interior of WCA-2A. Results showed that concentrations of nutrients and dissolved minerals in WCA canals were high, with some parameters exceeding state and federal water quality criteria. Marsh vegetation and sediments had a purifying "kidney effect," reducing inorganic nitrogen and phosphorus concentrations introduced into the marsh to background levels within a short distance from inflow structures. In contrast, concentrations of chlorides, sodium and silica, dissolved organic nitrogen and organic phosphate phosphorus, varied little between canal and marsh sites indicating that these elements were not immediately utilized by marsh vegetation as a nutrient source. Gleason (1974b) also suggested that deposits of ancient connate sea water trapped in the underlying aquifer was responsible for the high concentration of chloride and sodium, and high specific conductivity observed in EAA drainage waters, WCA canals and the interior WCA-2A marsh.

Millar (1981) provided the first synoptic assessment of hydrological and water quality conditions in all three WCAs. This study developed a preliminary materials budget for all three WCAs as well as a series of areal maps showing the distribution of nutrients and major ion concentration across each WCA. A total of 26 sampling sites (interior marsh and perimeter canal sites) were sampled in WCA-1, 21 sites in WCA-2A, while 35 sites were sampled in WCA-3A for 35 parameters including pH, conductivity, nutrients and major ions. Results of the two year (1978-1979) study showed that water quality within each WCA was largely a function of land use within the drainage basin. The physical design of each WCA, water level stages and the quality of inflow waters were also important factors determining water quality characteristics within each marsh. Highest nutrient concentrations were observed at sites in closest proximity to District pump stations or water control structures. Water quality improved markedly, away from inflow structures. Waters draining the EAA tended to be high in most of the chemical parameters measured. Highest nutrient loading occurred at northern WCA inflow points which drain the EAA. Rainfall was identified as a major contributor of phosphorus and a moderate contributor of nitrogen to the WCAs. Although rainfall nutrient concentrations were low, rainfall volume was large enough to contribute to substantial nutrient inputs into the system. The WCAs appear to function well as a natural nutrient filtration system. Although nutrient input loading was high, the WCA marsh exhibited evidence of high nutrient uptake and retention.

A short-term (ten-day) study of phosphorus uptake within the WCA-2A marsh was conducted by Davis (1982). Radioactively labeled ^{32}P was introduced into enclosures within a nutrient-enriched cattail stand and within a sawgrass stand containing background water quality. Results showed that over half of the labeled phosphorus was incorporated into marsh sediments after 10 days; 30% was assimilated by leaf litter at the enriched site, while only 12-15% was taken up by leaf litter at the background site. Living plant tissue incorporated only 2-4% of the introduced ^{32}P. These results indicate the relative importance of the sediments in initial phosphorus uptake as compared to living plants and leaf litter. A follow up study was suggested to look at longer term phosphorus uptake and recycling among different marsh components as well as determining whether the sediments act as a long-term phosphorus sink.

Populations of aerobic and facultative bacteria and fungi inhabiting leaf litter were studied by Reeder and Davis (1983) at both nutrient-enriched and background sites within WCA-2A. The presence of anoxic conditions at the nutrient-enriched site appeared to cause a shift in the microbial communities that were responsible for the decomposition of plant leaf litter. Litter microflora that could grow in the presence of oxygen appeared to be suppressed at the nutrient-enriched sites.

Ramifications of this effect on Everglades food chains are poorly understood but are probably significant since detrital food chains play a major role in most wetland ecosystems (see section: Impacts of Nutrients on the Everglades Ecosystem:Impacts on Microbiology).

Davis (1984, 1989, 1991) has conducted a number of long-term studies investigating the role of sawgrass and cattails as potential sinks for phosphorus and nitrogen along a gradient of surface water nutrient concentrations in WCA-2A. Results of these studies are discussed in detail in a later section of this report (see section: Impacts on Everglades Macrovegetation).

Investigations of the relationship between Everglades periphyton (algae) communities and water quality were conducted within the WCAs from 1978-1986 (Swift, 1981, 1984, 1986; Swift and Nicholas, 1987). Results showed that surface waters within WCA-2A, WCA-3A, WCA-3B and the perimeter marsh of WCA-1 were alkaline, and contained high concentrations of dissolved minerals. Highest concentrations of dissolved minerals were observed in WCA-2A which receives the majority of its water (58%) from surface water inflows draining the EAA and WCA-1. Concentrations of dissolved minerals in WCA-3A and WCA-3B were roughly one-third to one-half those reported in WCA-2A. In contrast, the interior of WCA-1 exhibited acid, soft water conditions and was largely isolated from EAA inflow waters. Interior marsh sites generally exhibited low concentrations of total phosphorus and inorganic nitrogen (nitrate+nitrite+ammonium ion). Rainfall represented the major source of nutrients for these interior marsh sites (Swift, 1981, 1984; Swift and Nicholas, 1987). Surface water inflows into WCA-2A contained high concentrations of nitrogen and phosphorus as well as chlorides from drainage of EAA organic soils. From 1978 to 1986, high levels of nitrogen and phosphorus were recorded downstream of the S-10 structures in WCA-2A. Water quality transects sampled over this nine-year period indicated that a nutrient front first present south of S-10C in 1978 had moved 1.5 -2.0 miles further south and was impacting the structure of Everglades periphyton communities exposed to these higher nutrient levels (Swift and Nicholas, 1987) (see section Impacts of Nutrients on the Everglades Ecosystem: Impacts on Everglades Periphyton).

Evaluation of the ecological response of WCA-2A to a reduction in the water regulation schedule and marsh drawdown indicated a number of changes in water quality and soil fertility associated with the changes in marsh hydrology (Worth, 1983, 1988). The initial drawdown increased the availability of some nutrients and other ions due to plant and soil decomposition, and leaching. During high water years, changes in marsh water quality were influenced more by source water inflows (rainfall and inflow water) than by the effects of the experimental drawdown. Areas adjacent to inflow structures (S-10 discharge structures and S-7 pump station) exhibited the highest concentrations of nitrogen and phosphorus observed in the study.

Belanger and Platko (1986) conducted an investigation of the sources and sinks of dissolved oxygen in WCA-2A surface waters. The northern section of WCA-2A, characterized by nutrient rich inflows and dominated by cattail vegetation, was reported to exhibit different dissolved oxygen dynamics as compared to pristine interior sawgrass stands and aquatic sloughs. Surface water dissolved oxygen levels were typically low at the nutrient enriched sites, while interior marsh sites exhibited large daily fluctuations in dissolved oxygen content. Sediment oxygen demand was the major oxygen sink identified at both sites. Atmospheric diffusion and periphyton photosynthesis were identified as the two major sources of oxygen at the interior aquatic slough site (see section: Impacts on Marsh Community Metabolism).

Pre-Drainage Water Quality: Prior to 1940, relatively little information exists concerning historical water quality conditions within the Everglades WCAs. The majority of this early information focused on water quality conditions within the groundwater or C&SF Project canals (Parker and Hoy, 1943; Parker *et al.*, 1955). Almost no information exists concerning the nutrient content of Everglades surface waters prior to 1960. Most of what is known about historical water quality conditions within the Everglades is based largely upon (a) the nutrient requirements and nutrient content of Everglades vegetation and soils as well as (b) inferences from information from water quality sampling sites that appear to be unaffected by water management practices or other anthropogenic effects.

Everglades peat soils, or histosols, represent the predominant soil type throughout the majority of the study area and are derived primarily from the growth death and decay of Everglades sawgrass (*Cladium jamaicense*) vegetation that usually forms over marl or limestone (Davis, 1943a). Early investigations of the mineral content of virgin Everglades peat found these soils to be high in nitrogen, low in phosphorus and potassium content (Hammer, 1929), and deficient in a number of important trace elements such as copper, manganese, zinc and boron (Allison *et al.*, 1927, 1950; Forsee, 1940). The low nutrient status of the historic Everglades is reflected in the predominant macrophyte and periphyton communities characteristic of the interior Everglades marsh where nutrient supplies are low. Sawgrass was and is still a major component of the WCA vegetation (Davis, 1943a; Loveless, 1959) and the dominance of this sedge is attributed, in part, to its low phosphorus requirements and in part to its fire adapted morphology (Steward and Ornes, 1975a). Analysis of the nutrient content of sawgrass communities (Steward and Ornes, 1975a,1983; Volk *et al.*, 1975; Davis and Harris, 1978), as well as studies of Everglades periphyton (Swift, 1981; Swift and Nicholas, 1987) show these plant communities to contain low concentrations of cellular phosphorus and that they appear to be well adapted to survive within an environment containing limited supplies of available phosphorus.

Another source of information is inferred from the analysis of water quality data collected from long-term water monitoring sites located deep within the interior of the Everglades that are presumed to be unaffected by water management practices or the influence of man. Water quality information collected from these sites show that during the wet season, surface waters are nutrient deficient with respect to inorganic forms of phosphorus and nitrogen (Swift, and Nicholas, 1987). Within the WCAs, average concentrations of soluble reactive phosphorus exist near or below 0.004 mg/l while average total phosphorus concentrations averaged near 0.01 mg/L. Low nutrient concentrations are most likely the result of uptake by organic sediments, native vegetation (periphyton and macrovegetation) and co-precipitation of phosphorus by calcium carbonate (Swift and Nicholas, 1987). Inorganic nitrogen concentrations varied widely in response to marsh water levels. Wet season concentrations existed at levels ranging between 0.02 - 0.10 mg/l (Davis *et al.*, 1987).

Calcium and bicarbonate, the principal inorganic ions present in Everglades surface waters tended to be higher in water covering marl soils in comparison to peat substrates. Present day analogs of the original pristine Everglades system can be found in the chemical analyses of water from the interior marsh of WCA-3A, interior WCA-3B, and within ENP at station P-34 (Waller and Earle, 1975; Waller, 1982a; Davis et al., 1987; Flora and Rosendahl, 1981, 1982; Swift, 1981, Swift and Nicholas, 1987).

Waller (as cited in Davis *et al.*, 1987) suggests that prior to 1934, water quality conditions in the southern Everglades was not affected by upstream alterations in hydrology or water quality. The Miami canal, which drains the EAA, was dredged to a point slightly north of its connection with the South New River Canal (Parker *et al.*, 1955) and thus did not transport large amounts of water downstream from developed agricultural areas located to the north. The three primary sources of water to the southern Everglades were overland flow from the upland Everglades, marshes located in the Big Cypress Preserve, and direct rainfall. Major water management changes occurred from 1950 to 1970 affecting the hydrologic regime of the southern Everglades (Leach *et al.*, 1972). The primary structural changes which potentially affected the water quality characteristics of the southern Everglades included construction and operation of pump stations S-8 and S-9, construction of the L-67A borrow canal and its connection to the Miami Canal, and construction and operation of the S-10, S-11 and S-12 structures. With these changes, more water could be channelized to flow more rapidly southward through WCA-3A into ENP from developing upstream agricultural and urban areas without the water quality benefits of nutrient uptake and assimilation originally provided by the Everglades marsh (Davis *et al.*, 1987).

Rainfall Water Quality in the WCAs. Direct rainfall apparently provided most of the water and nutrient supplies to the historical Everglades (Davis, 1943; Parker, 1974). Bulk precipitation, both dry-fall and rainfall, represents a major source of nitrogen and phosphorus inflow into the WCAs both historically and under current day conditions (Waller, 1975). Waller and Earle (1975) provide information concerning concentrations of phosphorus, nitrogen, organic carbon and conductivity for a number of selected WCA rainfall collection sites. After eliminating samples suspected of being contaminated, these data show bulk rainfall total phosphorus concentrations to average 0.032 mg/l at the S-9 pump station (WCA-3A) and the S-12A structure which provides inflow to ENP. Pump station S-5A, located in the northern portion of WCA-1 showed an average total phosphorus concentration of 0.093 mg/l for bulk rainfall (Waller and Earle, 1975, pages 51-53, tables 13, 14 and 15).

The most contemporary rainfall quality data available has been collected through the SFWMD bulk atmospheric deposition network with four long-term sites recording total phosphorus concentrations over a period of record ranging from 10 to 14 years. The SFWMD's rainfall quantity network consists of 273 sampling stations (**Figure 27**). Approximately half of these recorders are manually operated while the remaining are automatic recording devices.

A total of 12 sampling sites, largely concentrated in the eastern portion of the study area comprise the rainfall quality network as shown in **Figure 28.** For the past several years rainfall water quality data has been collected as wet and dry atmospheric deposition. Prior to May 1986, the majority of data collected was bulk precipitation, whose period of record began in 1974. Consequently, the majority of data collected to date is bulk atmospheric deposition. Four stations (B-50, OKEE, S-131 and S-2) make up the majority of the District's bulk rainfall data having a combined sample size of 652 observations (**Figure 27**). Bulk precipitation data consequently is currently superior to the more recent wet/dry rainfall data.

These long-term records show that average total phosphorus concentrations in bulk rainfall varies widely across south Florida (**Figure 28**). Minimum values occurred at Stations B-50 (West Palm Beach Field Station) with an annual

Figure 27. Location of SFWMD Rainfall Collection Sites for Quantity or Volume.

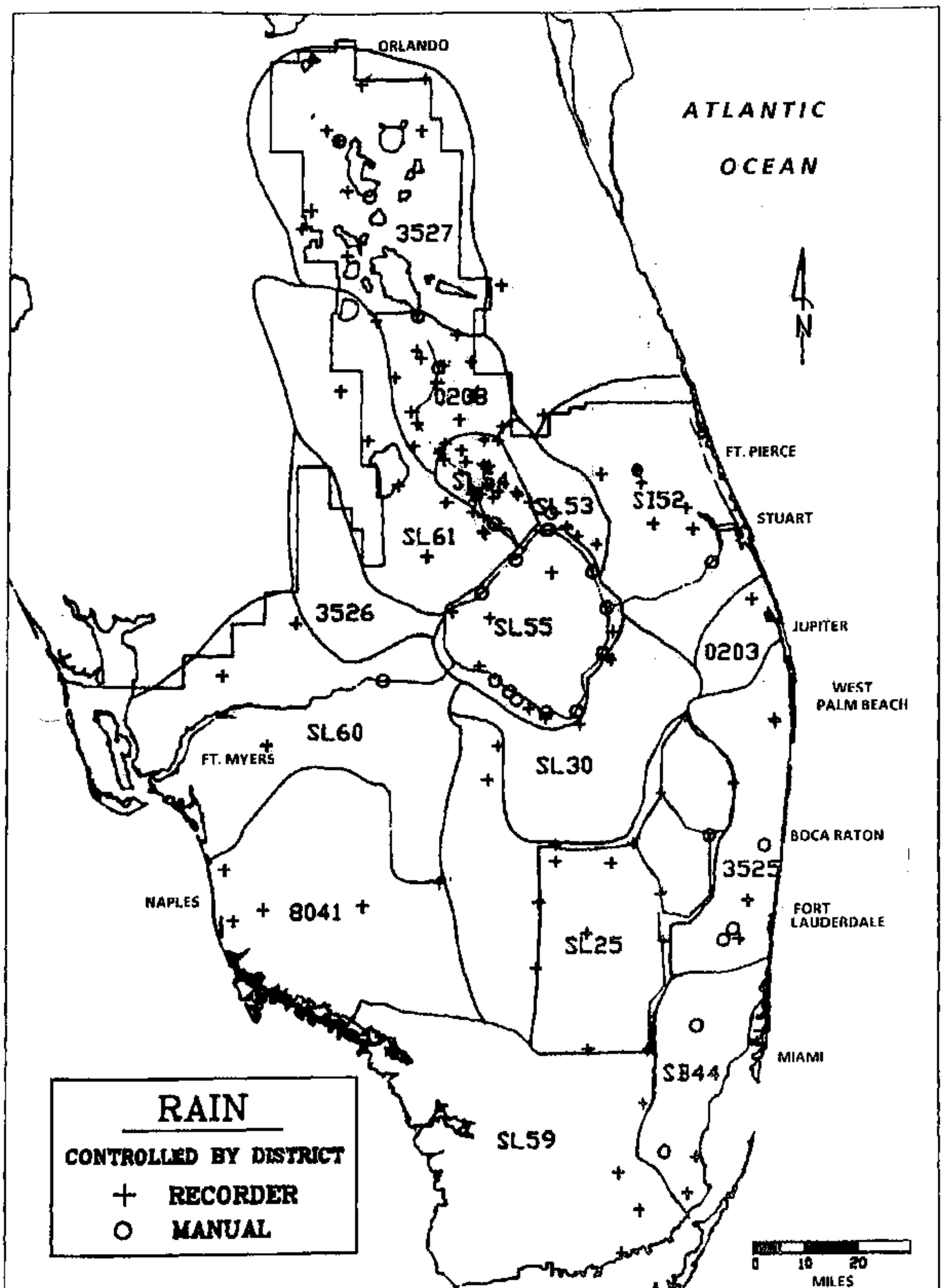
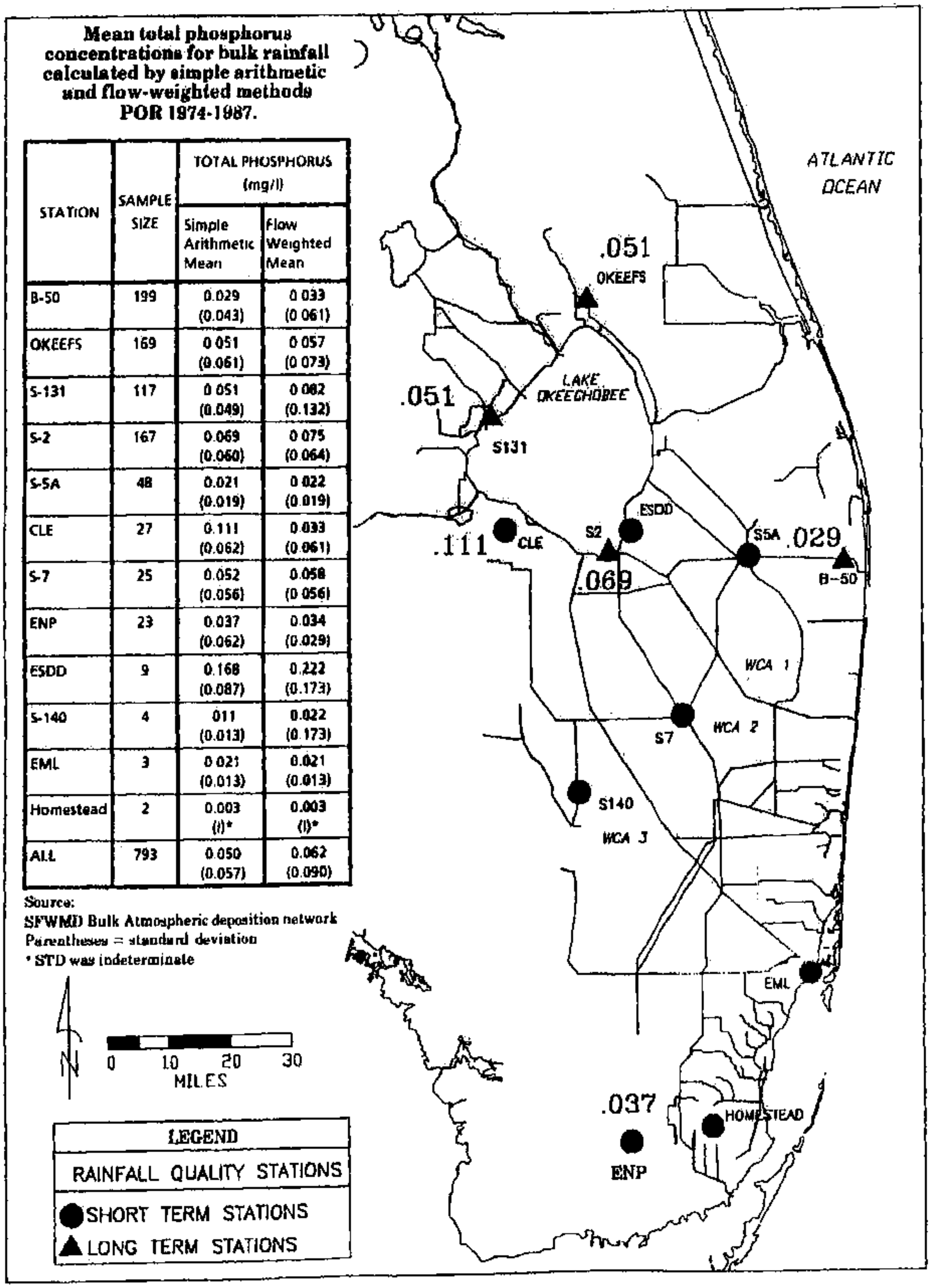


Figure 28. Location of Bulk Atmospheric Deposition sampling and Total P Concentrations for Bulk Rainfall

Mean total phosphorus concentrations for bulk rainfall calculated by simple arithmetic and flow-weighted methods POR 1974-1987.

STATION	SAMPLE SIZE	TOTAL PHOSPHORUS (mg/l) Simple Arithmetic Mean	Flow Weighted Mean
B-50	199	0.029 (0.043)	0.033 (0.061)
OKEEFS	169	0.051 (0.061)	0.057 (0.073)
S-131	117	0.051 (0.049)	0.082 (0.132)
S-2	167	0.069 (0.060)	0.075 (0.064)
S-5A	48	0.021 (0.019)	0.022 (0.019)
CLE	27	0.111 (0.062)	0.033 (0.061)
S-7	25	0.052 (0.056)	0.058 (0.056)
ENP	23	0.037 (0.062)	0.034 (0.029)
ESDD	9	0.168 (0.087)	0.222 (0.173)
S-140	4	011 (0.013)	0.022 (0.173)
EML	3	0.021 (0.013)	0.021 (0.013)
Homestead	2	0.003 (I)*	0.003 (I)*
ALL	793	0.050 (0.057)	0.062 (0.090)

Source:
SFWMD Bulk Atmospheric deposition network
Parentheses = standard deviation
* STD was indeterminate



(arithmetic) mean total phosphorus concentration of 0.029 mg/l reported over a 10 year period of record (1979-1989). The ENP site, located at the South Florida Research Center, recorded 0.037 mg/l over a shorter period of record (November 1987-April, 1989). The Clewiston field station (site CLE) located within the western portion of the EAA recorded the highest average annual total phosphorus value of 0.111 mg/l reported over a 17-month period (November 1987 to April, 1989). Rainfall collected at sites located around Lake Okeechobee and within the EAA, exhibited the highest total phosphorus concentrations for bulk precipitation within the study area. These data suggest that average total phosphorus concentrations for bulk rainfall at south Florida sites, uncontaminated by agricultural or other activities, averages approximately 0.03 mg/l. The 0.03 mg/l average represents the long-term annual total phosphorus concentration for bulk rainfall at District headquarters (Station B-50, 0.029 mg/l) and within the interior of ENP (South Florida Research Center, 0.037 mg/l). It is the least contaminated (lowest total phosphorus) rainfall of all the long-term rainfall collection stations within the SFWMD bulk atmospheric deposition network. The period of record for the B-50 site is 10 years and is contemporary (April, 1979 to April, 1989). By comparison, the average annual total phosphorus concentration in rainfall over South Florida is approximately 0.050 mg/l (**Table 16 and Figure 28**). This includes data collected at 12 stations with period of records ranging from less than one year to more than 10 years (823 observations).

Table 16. Estimates of Total Phosphorus Concentrations and Loadings for Bulk Rainfall for WCA-1, WCA-2A and WCA-3A.

Parameter	WCA-1	WCA-2A	WCA-3A
Area (sq. kilometers)	588	448	2,036
Annual Rainfall (cm)	122.6	116.8	113.8
Bulk TP rainfall concentration (mg/l)	0.047	0.049	0.050
Rainfall TP loading (metric tons/yr)	32	25	114
TP Areal Loading (metric tons/yr/km^2)	0.054	0.056	0.056

Source: SFWMD, unpublished data

Annual average total phosphorus concentrations at pump station S-2, recorded 0.069 mg/l over a 12-year period of record while pump station S-131 (10 year period of record) and the Okeechobee Field Station (14 year period of record) each averaged 0.051 mg/l (**Figure 28**). These data suggest that rainfall deposition within the EAA and around Lake Okeechobee may be contaminated by airborne soil particles, dust and ash resulting from agricultural operations within the EAA as well as seasonal fires which occur in the WCAs. In contrast, bulk precipitation data collected near the east coast (Station B-50) and within the interior marsh of ENP (South Florida Research Center) exhibited rainfall total phosphorus concentrations two to three times lower than values recorded within the EAA (S-5A was not considered due to its inconsistent sampling record and low number of observations).

A statistical procedure was employed to estimate phosphorus loadings and phosphorus concentrations in bulk rainfall for each WCA based on analysis of data collected from 12 sampling sites within the SFWMD bulk atmospheric deposition network (**Figure 28**). All period of record data were used for each of the 12 sites up to April 24,1989. Sample stations included B-50 (West Palm Beach Field Station), CLE (Clewiston Field Station), ENP (South Florida Research Center), OKEE (Okeechobee Field Station), five District pump stations (S-2, S-5A, S-7, S-131, S-140), Homestead Field Station, East Shore Drainage District, and the Experimental Meteorological Laboratory (EML) at Coral Gables. All data were screened for contamination by birds, frogs, algal growth or other potential contaminants. Ranking of all raw data indicated that values exceeding a total phosphorus concentration of 0.320 mg/l represented a potentially contaminated sample and was eliminated from the sample set.

Point data from the above 12 sites were used to find the areal distribution of total phosphorus in bulk rainfall for each WCA using a statistical computer analysis (USGS computer program K603) generally referred to as the "kriging" method (Skrivan and Karlinger, 1980). By specifying a theoretical semi-variogram and functional terms of an assumed underlying trend or drift, kriging provides unbiased estimates of variables in neighborhoods of autocorrelation. Given single observations and their spatial distributions in two-dimensions, the technique yields point estimates and point estimate variances at arbitrary locations. This method of interpolation has been applied to mining, geophysical exploration, descriptions of ground water flow (Skrivan and Karlinger, 1980) as well as the analysis of rainfall data (Gandin, 1970).

Table 16 presents mean values for bulk rainfall (dryfall + wetfall) total phosphorus concentrations as well as total phosphorus loadings contributed by rainfall for each of the three WCAs. These data were obtained from resultant grid point values computed by the USGS computer program. Results of these analyses indicated that total phosphorus contributions for bulk rainfall average approximately 0.05 mg/l (0.047-0.050 mg/l) over the period of record for the three WCAs. Annual total phosphorus loadings to WCA-1, WCA-2A and WCA-3A averaged 32, 25 and 114 metric tons per year, respectively, over the period of record. Rainfall nutrient concentrations presented in **Table 16** are about one-half the total phosphorus concentrations previously reported as the Florida statewide average (0.10 mg/l $\pm$ 0.08) in a USGS study (Irwin and Kirkland, 1980) conducted in the 1970's. This may be due to real differences between sampling periods, sample collection methods, data screening techniques or statistical methods employed. Data presented here are the most current available for total phosphorus concentrations for the south Florida region. Although **Table 16** gives the impression that WCA-3A receives a much larger share of rainfall phosphorus loading, comparison of areal loading rates show that each WCA receives approximately the same amount of phosphorus from rainfall per unit area with annual values averaging 0.09 metric tons per km^2.

Current Water Quality Conditions in the WCAs. Hydrological and environmental conditions within in the Everglades have changed a great deal in comparison to conditions that existed during the mid-19th century (Davis, 1943a; Parker *et al.*, 1955; Parker, 1974; Loveless, 1959; Alexander and Crook, 1984; Birnhak and Crowder, 1974; McPherson *et al.*, 1976). Historic overland sheet flow patterns have been disrupted and redirected as a result of construction of the C&SF project and the three WCAs (Leach *et al.*, 1972; Klein *et al.*, 1975; McPherson *et al.*, 1976) With the exception of rainfall and flows into the system from the eastern Big Cypress Basin, all inflows and outflows to the Everglades are regulated by a manmade water control system (C&SF Project). Today, water is routed quickly through a complex network of canals and impoundments, and flow is regulated by pumps and water control structures.

Nutrient concentrations measured in water discharged from Project structures into canals traversing and surrounding the WCAs are significantly higher than the concentrations measured at interior marsh sites in the WCAs. For example, averaged flow-weighted total phosphorus concentrations measured at interior sites over the period 1979-1988 at S-5A, S-6, S-7, S-8 and L-3 structures were 0.19, 0.12, 0.10, 0.20 and 0.25 mg/l, respectively. In contrast, Waller and Earle (1975) reported two-year median concentrations for total phosphorus ranged from 0.01 to 0. 02 mg/l at interior marsh sites while Swift and Nicholas (1987) and Reeder and Davis (1983) measured total phosphorus concentrations anywhere from below detection ($\leq$0.004 mg/l to 0.022 mg/l at pristine sites. Therefore, average flow-weighted concentrations of total phosphorus may be ten times as high as average interior WCA wetland concentrations.

These water management structures drain the EAA which includes about 700,000 acres of rich organic soils (formerly Everglades marsh) that has largely been converted to intensively managed farm fields. Water discharged from these Project structures contain high concentrations of nitrogen and phosphorus, as well as chloride, sodium, calcium carbonate, trace metals and occasional pesticide contamination. (Gleason, 1974; Waller and Earle, 1975; Klein *et al.*, 1975; Lutz, 1977a,b; CH_2M-Hill 1978; Millar, 1981; Pfeuffer, 1985; Pfeuffer (in press).

Project canals in the EAA provide flood protection and drainage, supply irrigation water, make regulatory releases to Lake Okeechobee, and transfer water from storage in Lake Okeechobee to the WCAs. The first of these two functions are of concern with respect to nutrient discharges.

EAA farmland consists of organic soils, called histosols, which require intensive flooding and drainage management. Histosols were formed under anaerobic, water-logged conditions. Drainage and aeration of organic soils causes shrinkage, consolidation and biological oxidation leading to subsidence (Cox *et al.*, 1988). Soil subsidence along with frequent flooding and drainage of the soils results in the presence of nitrogen and phosphorus into EAA drainage canals (Morris, 1975; CH_2M-Hill, 1978).

The need for intensive irrigation and drainage and the economics and size of EAA farms has led to the creation of a complex pattern of ditches and pumps designed and operated to speedily move large amounts of water onto and off EAA farmlands. The water comes from the lake or precipitation and it drains eventually into Project structures and is pumped southward into the WCAs. Soil oxidation,water table control (to store water in organic soils or to pump off water if a major rainfall event threatens), and application of fertilizers all contribute to the presence of nutrients in waters discharged from the EAA into Project canals.

Additional water of lesser quality than that found at interior marsh sites is discharged from tributary basins to the east and west into the WCAs (SFWMD, 1982, 1983, 1984a, 1984b). Water quality conditions and flows from these basins are not well documented. General descriptions of land use and water management of the eastern and western tributary basins are provided in Part II of this volume (Basins East of the WCAs and Basins West of the WCAs).

<u>Water Quality at Interior WCA Marsh Sites.</u> For the purposes of this report, interior marsh sites are defined as those areas of the Everglades WCA marsh that are far removed from the influences of surface water inflows from District water control structures or other human influences. The principal nutrient source for these sites appears to be contained in rainfall. Data used to characterize water quality conditions at interior marsh sites located in WCA-1, WCA-2A, WCA-3A and WCA-

3B were derived from five District technical publications (Swift, 1981, 1986; Swift and Nicholas, 1987; Worth, 1983, 1988).

Dissolved Minerals and pH. The mineral content and pH of interior marsh surface waters varies widely among the three WCAs. These differences are associated with the source of inflow water, current land use practices associated with each drainage basin and the routing of water through the WCAs.

Surface waters within the interior marsh of WCA-1 exhibit low concentrations of dissolved minerals (soft water), poor chemical buffering capacity and low pH (5.7) (**Table 17**). Compared to other WCAs, the low mineral content and acid pH of WCA-1

Table 17. Average pH Conductivity, and Major Ion Concentrations at Interior WCA and ENP Marsh Sites Far Removed from the Influences of District Water Control Structures.

Parameter	WCA-1 (1)	WCA-2A (1)	WCA-3A (1)	WCA-3B (2)	ENP (3)
pH	5.7	7.1	7.0	7.6	7.7
Conductivity (umhos/cm)	112	1050	333	512	478
Alkalinity ($CaCO_3$, mg/l)	16	245	132	175	161
Chloride (mg/l)	22	174	28	56	46
Sodium (mg/l)	12	121	18	37	30
Calcium (mg/l)	6	67	47	52	58
Magnesium (mg/l)	1.5	28	4	8	7.5
Potassium (mg/l)	0.6	6.5	1.1	1.9	1.8
Silica (mg/l)	4	19	7	7.6	nd
Sulfate (mg/l)	9	39	12	5	4.2
Total Iron (mg/l)	0.2	0.1	0.5	0.4	nd
number of samples (n)	121	125	117	17	61

Sources: (1) Swift and Nicholas (1987) POR 1978-1983; (2) Swift (1986) unpublished data, POR 1982-1983; (3) Central Shark River Slough, Station P-33, POR 1959-1983, USGS records.

surface waters is believed the result of three factors: (1) WCA-1 is entirely encircled by an interior perimeter canal (L-7, L-39, L-40) which directs the majority of inflow around the marsh perimeter; (2) Ground level elevations within the interior of WCA-1 are slightly higher than the marsh's perimeter due to peat subsidence resulting from canal construction, thus, higher ground level elevations, and the routing of inflow water around the marsh perimeter tends to restrict highly mineralized canal water from penetrating the marsh interior; and (3) The high water holding capacity and capillary action of the deeper WCA-1 peat soils (up to 4 meters in depth) effectively hold large volumes of surface water derived from rainfall and isolates it from more mineralized groundwater. These three factors tend to isolate interior WCA-1 surface waters from mixing with mineralized water from canals or ground water. As a result, surface waters within the interior of WCA-1 exhibit low mineral content indicating that rainfall is the primary source of water for the interior of WCA-1 (Swift and Nicholas, 1987).

In sharp contrast, highest concentrations of dissolved minerals (bicarbonate, calcium, chloride and sodium) occur in WCA-2A (**Table 17**). Unlike WCA-1, WCA-2A lacks interior perimeter canals. Highly mineralized, nutrient-enriched canal water is discharged directly across the northeast section of the WCA-2A marsh. WCA-2A receives about 59 percent of its inflow water from inflows through (a) the four S-10 water control structures located on the L-39 levee (Hillsboro Canal) which drains the EAA and WCA-1 and (b) pump station S-7 located on the western levee of WCA-2A. The S-10 structures receive a mixture of inflow water from WCA-1 and highly mineralized, nutrient-enriched canal water derived from drainage of the EAA. Surface waters draining the EAA are high in chloride, sodium and calcium carbonate as well as a number of other mineral constituents (potassium, magnesium, sulfate and silica) in contrast to the calcium carbonate-dominated surface waters that are characteristic of the interior of WCA-3A, WCA-3B and ENP (Table 17). WCA-2A waters are typically slightly alkaline with an average pH near 7.1 (Gleason, 1974b; Waller and Earle, 1975; Swift and Nicholas, 1987).

Surface water alkalinity and hardness (dissolved minerals) values within the interior of WCA-3A and WCA-3B were one-half those measured in WCA-2A and were comparable to values recorded within the interior of ENP at station P-33 in central Shark River Slough (**Table 17**). Surface waters within the southern region of the Everglades have often been described as the "calcium carbonate type" (calcium is the dominant cation) and are influenced by precipitation and weathering of the limestone bedrock (Gleason, 1972; Gleason and Spackman, 1974; Flora and Rosendahl, 1981).

Although the origin of surface water inflow represents the primary factor influencing the mineral content of each WCA, seasonal variations in marsh hydrology, dilution by rainfall or concentration by evapotranspiration also affect the mineral content of interior WCA marshes (Waller and Earle, 1975; McPherson *et al.*, 1976; Swift and Nicholas, 1987).

Nutrients: During the wet season, surface waters within the interior marsh water are typically nutrient deficient with soluble reactive phosphorus (orthophosphate) present at very low concentrations, usually near or below the limit of analytical detection (<0.004 mg/l). Annual total phosphorus values from 1978 to 1983 averaged between 0.009 - 0.014 mg/l at interior WCA sites (Swift and Nicholas, 1987). Inorganic nitrogen (nitrate+nitrite+ammonium) values were relatively low during the wet season with average concentrations of less than 0.12 mg/l (**Table 18**).

Table 18. Average Nutrient Concentrations at Interior WCA Marsh Sites.

Parameter	WCA-1 (1)	WCA-2A (1)	WCA-3A (1)	WCA-3B (2)
Inorganic N (mg/l)	0.09	0.12	0.09	0.06
Total N (mg/l)	2.53	2.86	2.15	1.36
Organic N (mg/l)	2.41	1.71	2.04	1.26
Total P (mg/l)	0.011	0.014	0.009	0.007
Ortho PO_4 (mg/l)	<0.004*	<0.004	0.004	<0.004
number of analyses (n)	121	125	117	17

Source: (1) Swift and Nicholas (1987), POR 1978-1983; (2) Swift (1986) unpublished data, POR 1982-1983.
* = Limit of chemical detection

Average total phosphorus concentrations within these interior wetland ecosystems are comparable to values recorded from a number of oligotrophic Florida lakes (Swift and Nicholas, 1987). On a seasonal basis, total phosphorus concentrations at interior marsh sites showed relatively little change over time. Low levels were encountered during high and low water periods. Highest total phosphorus concentrations were generally observed when the marsh was drying, and immediately following reflooding (Swift and Nicholas, 1987). Inorganic nitrogen concentrations were low when the marsh was flooded, but increased markedly in the late dry season as water levels receded. The increase in nitrogen was probably due to organic matter decomposition and associated release of ammonium and nitrates into the shallow water column. Large releases of ammonia and nitrates are a common phenomena of peat-forming marshes which undergo periodic drying (Richardson *et al.*, 1978; Klopatek, 1978; Worth, 1983).

In contrast, total and organic nitrogen concentrations at interior marsh sites were comparable to eutrophic Florida lakes. Total nitrogen concentrations at interior marsh sites averaged 1.3 to 2.9 mg/l (**Table 18**). The origin of these higher nitrogen levels is not well understood. However, possible sources include rainfall, decomposition of periphyton, organic peat, leaf litter and leaching from living plants. High concentrations of total and organic nitrogen commonly occur in temperate and south Florida wetlands (Richardson *et al.*, 1979; Davis, 1981).

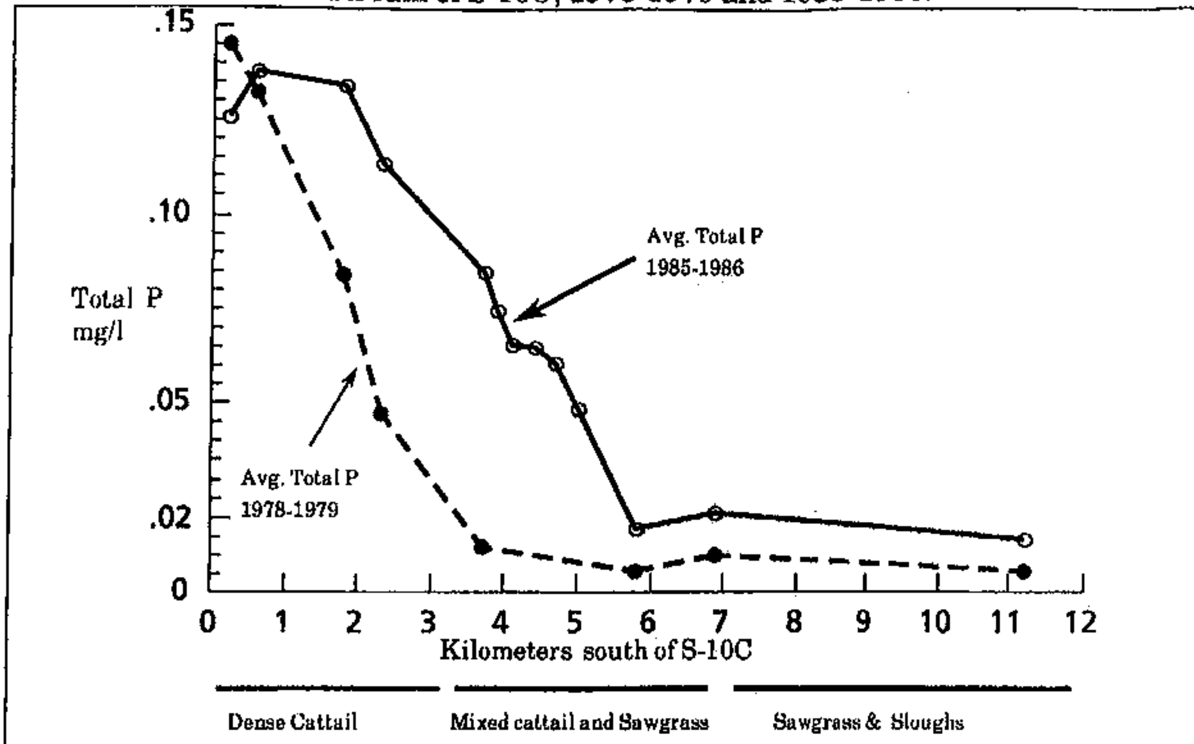
A review of the literature indicates that the phosphorus content of Everglades surface waters, peat soils, periphyton and sawgrass communities is low throughout the interior marsh and that native plant communities have become adapted to limited nutrient supplies over a period of 4,500 years. Rainfall represents the major source of nutrients for the interior marsh area within all three WCAs (Waller and Earle, 1975; McPherson *et al.*, 1976; Swift and Nicholas, 1987).

Water Quality Characteristics of the WCA Perimeter Marsh. Water quality data collected from the northern Everglades WCAs during the late 1970s and early 1980s indicate that major water quality changes have taken place downstream from District water control structures within WCA-2A. The discharge of nutrient-enriched canal water across the the northern portion of WCA-2A has resulted in a nutrient gradient of decreasing phosphorus concentration downstream of the S-10 discharge structures. This gradient was first detected by Gleason (1974) and later by Swift (1981). Water quality studies performed downstream of the S-10 structures between years 1978 and 1982 indicated that this nutrient gradient had now penetrated the WCA-2A marsh approximately 2.5 to 3.0 kilometers further downstream from S-10C than first recorded in 1978 (Swift and Nicholas, 1987). Long-term (1978-1986) water quality transects conducted downstream of S-10C show this expanding phosphorus gradient as presented in **Figure 29.**

Between 1976 and 1988, SFWMD staff have collected over 2,220 surface water quality samples in conjunction with a series of biological studies conducted within WCA-2A (Davis and Harris, 1978; Millar, 1981; Reeder and Davis, 1983; Davis, 1982, 1984, 1990; Toth, 1987, 1989; Worth, 1983; 1988; Swift, 1981; Swift and Nicholas, 1987; SFWMD Water Quality Monitoring Network). District staff have organized these data into one data set in an effort to examine the spatial and temporal trends in total phosphorus concentrations downstream from the S-10 structures within the northern portion of WCA-2A. The specific question addressed in this analyses was (1) does there exist a statistically significant increase in total phosphorus concentrations downstream from the S-10 structures along a north-south gradient previously identified by Swift and Nicholas, 1987 and (2) has this gradient changed over time?

Because the data was collected at 35 different site locations by different investigators within different or overlapping time periods, these data were pooled into 6 separate zones located at various distances downstream from the S-10 inflow structures. The six zones were organized to include Zone 1: sites located less than 2.0 km downstream from S-10's, Zone 2: sites located 2.1-2.9 km downstream; Zone 3: sites located 4.0 to 4.9 km downstream, Zone 4: sites located 5.0 to 7.0 km downstream, Zone 5: sites located 7.0 to 9.0 km downstream and Zone 6: one site (2-17 gage) located 12.0 km downstream from S-10A, S-10C or S-10D. Results of these analyses show;

Figure 29. Comparison of Average Total Phosphorus Concentrations Downstream of S-10C, 1978-1979 and 1985-1986.



Source: SFWMD Unpublished Data

Zone 1 (0-2.0 km downstream): Between 1978 and 1983 average annual total phosphorus concentrations fluctuated between 0.130 mg/l (1979) - 0.324 mg/l (1981). No consistent temporal trends were evident at these sites located closest to the S-10 discharge structures.

Zone 2 (2.1-2.9 km downstream): Total phosphorus concentrations increased significantly (P<0.05) from 1977 to 1988. From 1977-1979 average annual total phosphorus concentrations doubled within Zone 2 of the WCA-2A marsh, increasing from 0.066-0.077 mg/l up to 0.136-0.144 mg/l during 1986-1988. However,highest levels were recorded during the drought years of 1981 and 1985 with values exceeding 0.2 mg/l.

Zone 3 (4.0-4.9 km downstream): Average annual total phosphorus concentrations within Zone 3 ranged from 0.019 - 0.025 mg/l from 1977-1980, increasing to 0.140 mg/l in 1982, and declining to 0.052-0.072 mg/l during 1986-1988. Total phosphorus concentrations were significantly (P<0.05) higher during the late 1980's as compared to the late 1970's.

Zone 4 (5.0-7.0 km downstream): Average annual total phosphorus concentrations during 1978-1980 averaged 0.008-0.10 mg/l. The levels increased significantly (P<0.05) during 1986-1988 to 0.048-0.049 mg/l.

Zone 5 (7.0-9.0 km downstream): Average annual total phosphorus concentrations during 1978-1980 averaged 0.007-0.008 mg/l, dramatically increasing in 1981-82 to 0.044-0.059 mg/l (a 6-7 fold increase) and declining to 0.023-0.027 mg/l from 1986-1988.

Zone 6 (12.0 km downstream): With but one exception, the 2-17 gage site showed no distinct temporal change in total phosphorus concentrations between 1979 and 1988 as total phosphorus ranged between 0.005-0.014 mg/l. The only exception was 1986 where total phosphorus values increased to 0.072 mg/l.

Results of these analyses indicate that between 2 and 9 km south of the S-10 structures, total phosphorus concentrations have significantly increased over time as well as downstream from the S-10 structures. These data support a number of earlier observations that nutrients levels have increased downstream of these water control structures over time (Swift and Nicholas, 1987; LOTAC-II, 1988) and that a "nutrient front" has progressed further south into WCA-2A during the 1980's.

Current information indicates that vegetation communities within WCA-2A have been affected by elevated nutrient concentrations in combination with a number of other factors such as hydroperiod changes, effects of drought and the possible impact of fire. The source of these elevated nutrient levels are thought to be primarily the drainage of agricultural lands located within the S-5A, S-6 and S-7 basins. The Everglades Agricultural Area (EAA) is the single most likely and largest source of nutrients discharged into the WCAs according to the WCA water and nutrient budgets presented in a later section of this plan. (see Nutrient Budget section). On the average, water management structures which drain EAA farm lands (S-5A, S-6, S-7 and S-8) have generated 47 percent (202 metric tons) of the phosphorus load and 58 percent (7,090 metric tons) of the nitrogen load to the WCAs over the 10 year period of record

In comparison to background concentrations of nutrients observed at interior marsh sites, surface waters draining the EAA contain high concentrations of nitrogen and phosphorus most probably resulting from soil subsidence due to drainage of these agricultural lands. Elevated nitrogen concentrations are derived primarily from the biological oxidation and mineralization of organic (peat) muck soils, while relatively high phosphorus concentrations result from a combination of soil subsidence and fertilizer use within the EAA. Typical nutrient concentrations within EAA drainage canals are contrasted with ambient interior marsh nutrient concentrations within WCA-2A as shown in **Table 19**.

Table 19. Comparison of Average Nutrient Levels at WCA-2A Inflow Structures (S-10C) and the Interior Marsh of WCA-2A.

Parameter	Ave. S-10C inflow water	Interior marsh WCA-2A
Total N (mg/l)	5.00	3.05
Inorganic N (mg/l)	0.51	0.12
Total P (mg/l)	0.126	0.012
Ortho PO_4 (mg/l)	0.085	<0.004

Source: SFWMD, unpublished data; Swift and Nicholas, 1987, POR 1978-1983.

In addition to high concentrations of dissolved minerals and nutrients, surface water inflows to WCA-2A also contain elevated concentrations trace metals (copper, zinc, lead and iron) as compared to interior marsh sites unaffected by agricultural surface water runoff (Lutz, 1977a, 1977b; Dickson *et al.,* 1978; CH_2M-Hill, 1978).

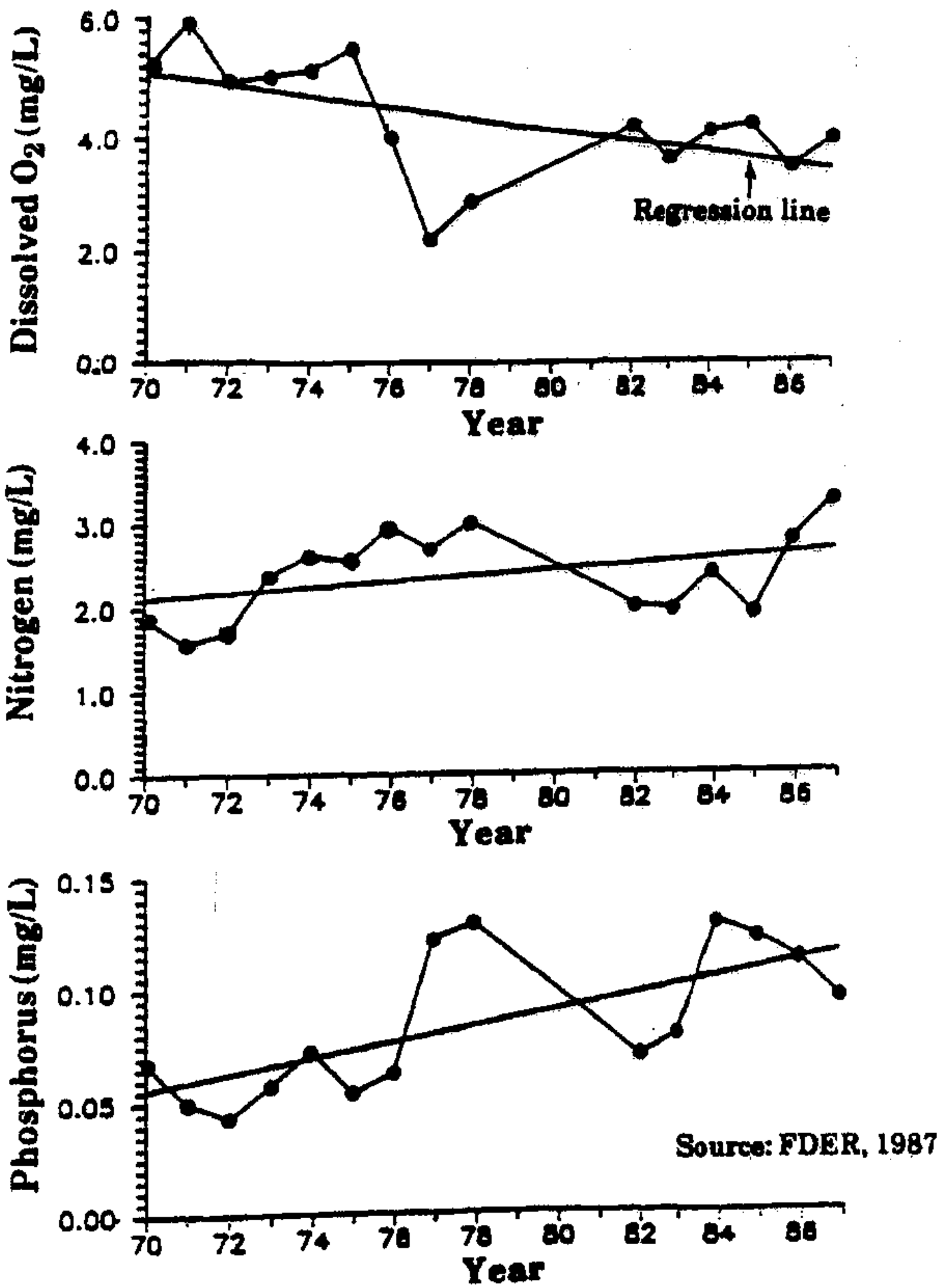
Traces of pesticides are also occasionally found as contaminants of EAA drainage water (Kolpinsky and Higer, 1969; Waller and Earle, 1975; Milleson, 1980; Pfeuffer, in press; Hand *et al.,* 1987). However, the major ecological concern is phosphorus loading. High concentrations of this element have been shown to cause major changes in the species composition and growth rates of Everglades periphyton (Swift and Nicholas, 1987). High phosphorus concentrations in Everglades surface waters have been shown to cause a shift in the species composition of native Everglades periphyton to less desirable "pollution tolerant" algal species. Nutrient dosing studies conducted in ENP (Flora *et al.,* 1987) and enclosure experiments performed in WCA-3A (Steward and Ornes, 1975b) have shown that the addition of high phosphorus concentrations to Everglades surface waters can result in the elimination of the native Everglades periphyton mat community. High nitrogen and phosphorus concentrations are also thought to be an important factor influencing the dominance and spread of cattails in the northern portion of WCA-2A over the past decade. High nitrogen and phosphorus concentrations allow cattails to out-compete native sawgrass vegetation during years of high nutrient inflows (Davis, 1991). Areas of the marsh that are primarily affected are those sites located directly downstream of water management inflow structures. The majority of these water management structures were built over 30 years ago as part of the C&SF Project to provide flood control and water supply benefits to the region.

State Water Quality Assessment. In 1987, the DER performed an assessment of water quality data for the WCAs contained in the database STORET for the period of record 1970-1987 (Hand *et al.,* 1987). This assessment included analysis of over 5,000 observations from 61 sites. Of these, data from 44 sites were sampled by the USGS, 10 sites were sampled by the DER, four sites were monitored by the District, and three sites were sampled by the EPA. A group of 24 water quality parameters, including water clarity, dissolved oxygen, oxygen demand, pH-alkalinity, trophic status, bacterial counts, biological diversity, conductivity, un-ionized ammonia and fluoride were used to evaluate the water quality conditions and produced a general water quality index.

Two major conclusions were drawn from these analyses as follows; (1) Four of the pollution categories indicated moderate to severe water quality problems, including high nutrient concentrations, high biological oxygen demand, low dissolved oxygen concentrations, and low macroinvertebrate biological diversity; (2) Water quality within rim [perimeter] canals were"significantly worse" than water quality conditions exhibited at interior marsh sites (Hand *et al.,* 1987). Problems within the rim canal were also associated with nutrients, biochemical oxygen demand and dissolved oxygen. Interior marsh sites generally showed overall good water quality as ranked by the water quality index while rim canals generally ranked fair.

Comparison of state numerical water quality criteria (Chapter 17-3, FAC) and WCA STORET data showed the occurrence of low dissolved oxygen concentrations (below 5 mg/l) at both canal and interior marsh sites, but indicated such analysis must take into account natural background conditions. The DER study also indicated that state water quality criteria (Chapter 17-3 F.S.) for dissolved oxygen, pH, specific conductance and bacteria was exceeded on several occasions (Hand *et al.,* 1987). The 1987 DER report also indicated that concentrations of nitrogen and phosphorus in canal inflow waters exceeded ambient levels recorded at interior marsh sites. The STORET data was also analyzed for trends by plotting annual averages for long-term period of record stations. **Figure 30** shows the trend analysis for WCA-1 rim [perimeter] canal stations. Examination of these plots indicate a long-term trend of degrading water quality within WCA-1 perimeter canals for dissolved oxygen, total nitrogen and total phosphorus (Hand *et al.,* 1987).

Figure 30. Trend analysis for water quality constituents in WCA-1 perimeter canals.



The 1987 DER report also identified the occurrence of pesticides within WCA surface waters and sediments. Analyses of 67 compounds at nine sites revealed, that except for the compound atrazine, none of the other 66 compounds were detected within WCA surface water samples. Atrazine was detected at the S-8 and S-7 pump stations which drain agricultural lands and flow into the northern portions of WCA-2A and WCA-3A, respectively. Observed concentrations were 0.77 ug/l at S-8 and 2.91 ug/l at S-7. At present, no DER or EPA guidelines exist for atrazine in drinking or surface waters. A pesticide scan of collected sediment samples revealed that three pesticide compounds -- 2,4,D; ametryne; and methamiodophos -- occurred at pump stations S-6 and S-31, the L-3 well bridge and the U.S. 41 bridge. Currently no quality criteria exist for pesticides within sediments.

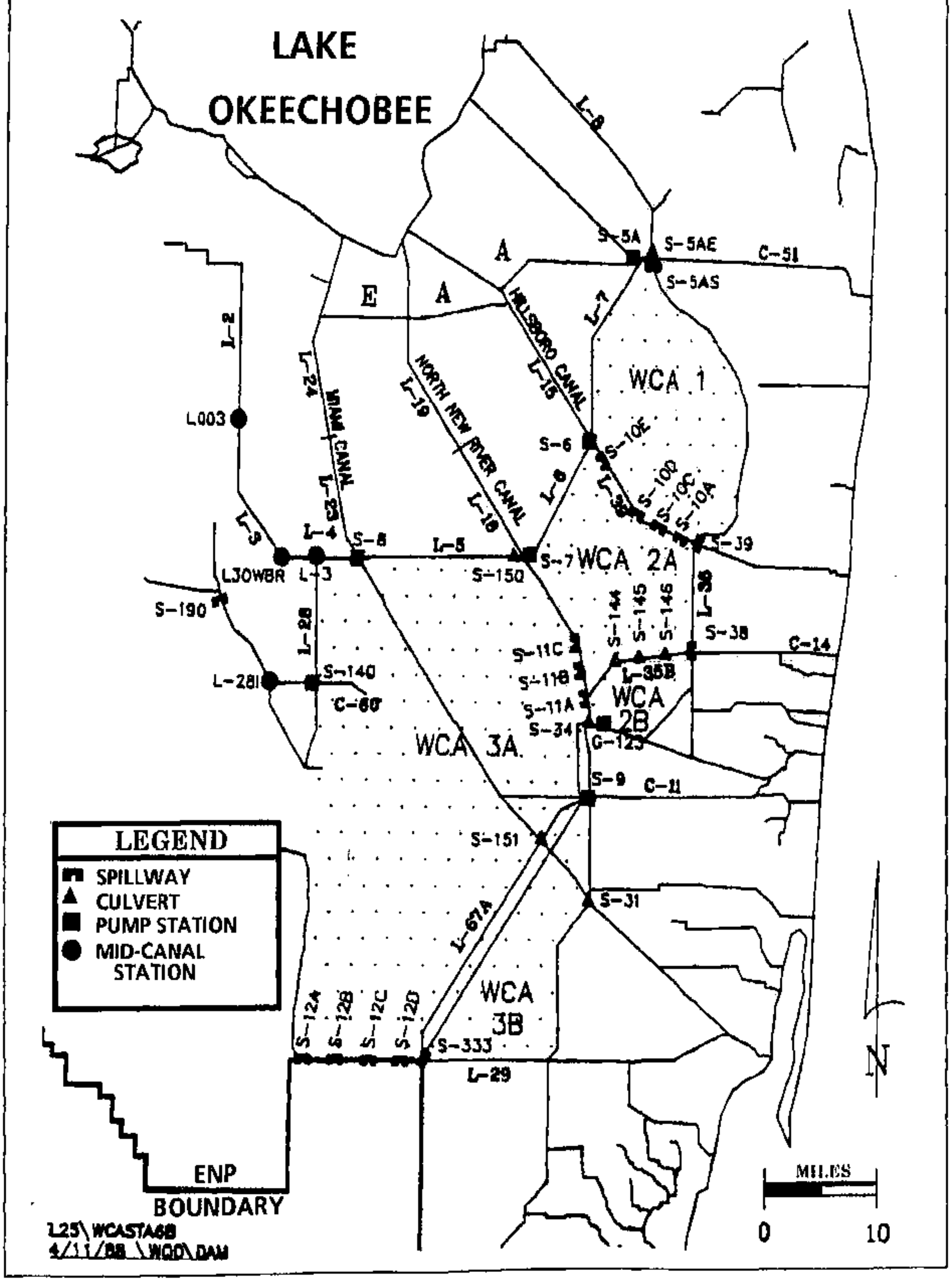
The water quality characteristics of this region were updated in a 1988 DER report (Hand *et al.*, 1988) which identified the L-8, West Palm Beach, Hillsboro, North New River and Miami canals south of Lake Okeechobee to the L-4 and L7 canals as;

> "...exhibiting poor water quality with extremely high nutrients and low D.O. values. Pesticides, BOD, bacteria and suspended solids have also been identified as problems. Agricultural runoff and the overflow from seepage from huge sugar cane mill retention ponds provided the pollutant loading to these canals ... In addition, between the L-8 and West Palm Beach canals, sludge spreading operations may further impact these waterways...The West Palm Beach canal also has a toxicity problem with fishkills occurring after heavy rains drain from the Chemair Spray hazardous waste site [near the city of Pahokee]. Canals bordering the conservation areas [WCAs] generally have very low D.O. concentrations typical of marsh waters. Nutrient levels at the perimeter of the marsh are somewhat elevated, probably due to detritus breakdown as well as agricultural drainage."(Hand *et al.*, 1988).

Sources of Phosphorus. A water and nutrient budget was prepared by the SFWMD in support of this plan to determine the primary sources of nutrient inflows into the WCAs. This detailed materials budget is based on data collected over a ten year period of record (October 1, 1979 to September 30, 1988) using USCOE and USGS discharge, rainfall and evapotranspiration records, as well as SFWMD water quality and quantity databases. Three hydrologic characteristics (rainfall, evapotranspiration and discharge volumes) and two water quality constituents (total nitrogen and total phosphorus concentrations) were collected from each of 20 major discharge structures, eight minor water control structures and four long-term rainfall collection stations as shown in **Figure 31.** These data were examined statistically and graphically. Results of these analyses are summarized in **Figure 32** and **Table 20.** In **Appendix B**, Tables B-25 through B-59 provide a summary of hydrologic and nutrient budgets calculated for each WCA by year (1979-1988). For details concerning water quality collection methods, calculation of rainfall and inflow/outflow nutrient loadings, storage changes, areal nutrient loading rates, areal nutrient retention rates, water residence times and percent retention for nitrogen and phosphorus for the WCA nutrient budget, see **Appendix B.**

WCA Hydrologic Budget. **Figure 32** provides a graphic summary of the water budget for all three WCAs for the ten year period of record based on water year (Water Year 1979-1988 = October 1, 1978 to September 30, 1988). Direct rainfall represents the largest source of water for all three WCAs representing 66 percent (2.8 million acre feet) of all water entering the area annually. Evapotranspiration accounted for the largest loss of water from the system averaging 76 percent or 3.3 million acre-feet annually. Drainage waters from the EAA represented the largest source of surface water inflows into the WCAs. Four major pump stations (S-5A, S-6, S-7 and S-8) collectively accounted for 23 percent (1.0 million acre-feet) of all inflows

Figure 31. Location of sampling stations for the WCA inflow/outflow water quality monitoring program.



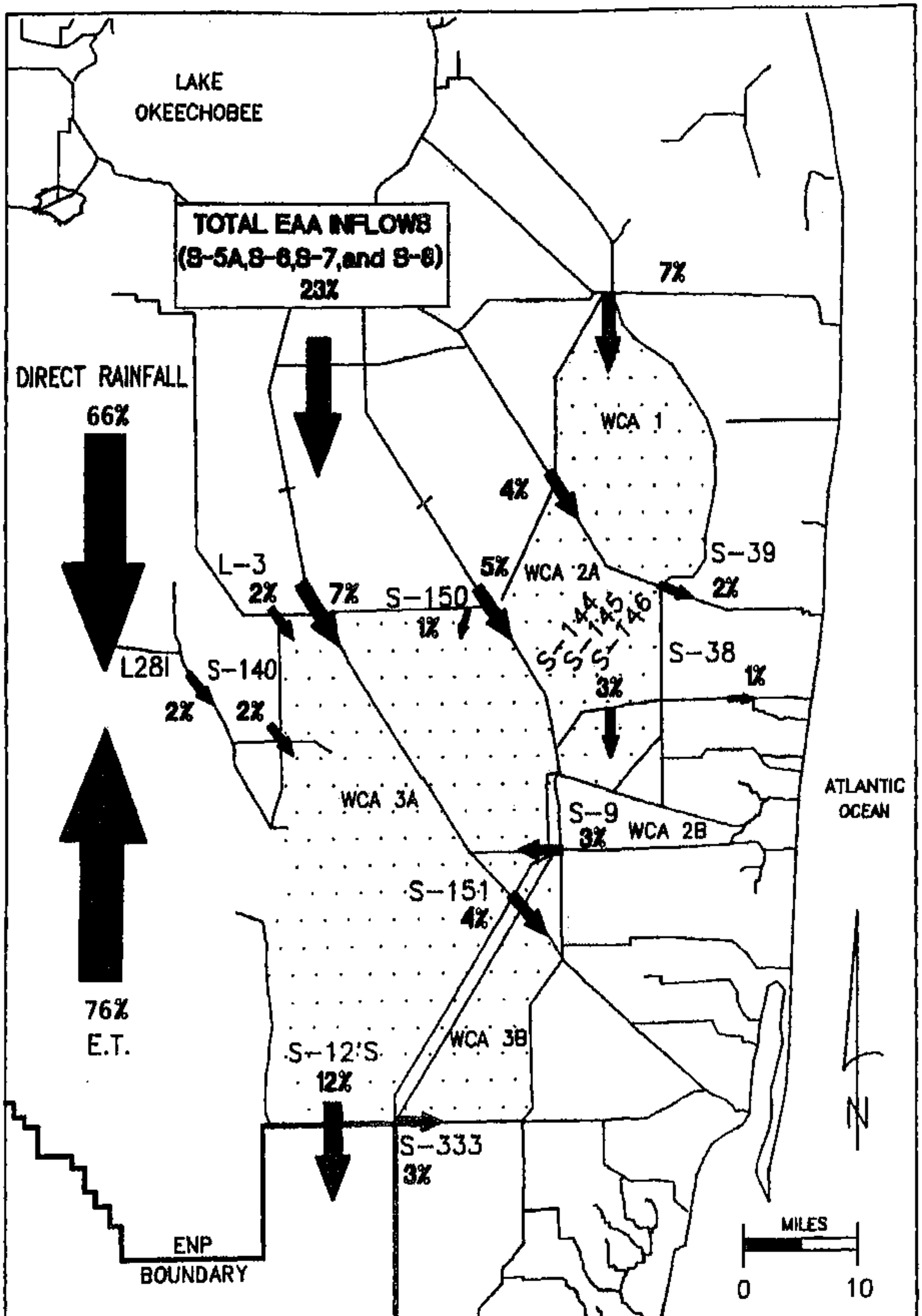


Figure 32. Major sources of water inflow/outflow in the WCAs.

into the WCAs over the period of record (**Table 20**). Other important inflows include the S-9 basin (3 percent), which drains largely urban lands in western Broward county; pump stations S-140, the L-3 and L-28 interceptor canal which collectively account for 6 percent of all inflows into the western WCA-3A marsh.

Major outflows from the system include the four S-12 structures (S-12A, S-12B, S-12C, and S-12D) and S-333 which account for 15 percent (0.623 million acre feet) of all outflows from the system over the ten-year period of record (**Figure 32**). Other important outflows include water control structure S-151 (4 percent) located on the Miami Canal, S-39 (2 percent) located on the Hillsboro canal, S-38 (1 percent) and S-150 (1 percent).

WCA Nutrient Budget. **Table 20** presents a detailed summary of the annual nutrient budget prepared for all three WCAs (WCA-1 +WCA-2A + WCA-3A) using the same ten year period of record (October 1, 1978 to September 30, 1988) based on water year. These analyses include average nutrient loadings for rainfall and each of the 20 inflow/outflow structures, areal nutrient loading rates, areal nutrient retention rates, water residence time and evapotranspiration volumes for the entire system. **Figure 33** presents a general overview of the major sources of phosphorus inflow and outflow within the WCAs over the period of record. **Table 21** provides a brief summary of annual average total phosphorus loading, flow weighted concentrations, and annual water inflows for each of the 8 major water control structures which provide inflow into the WCAs.

The largest source of nutrients identified in **Figure 33** originate from surface waters draining the Everglades Agricultural Area (EAA) located north and west of the WCAs. Surface water drainage of the EAA through S-5A, S-6, S-7, S-8, and S-150 represents 48 percent (205 metric tons/yr) of all phosphorus inflows to the WCAs, while direct rainfall (bulk precipitation) accounts for 40 percent (172 metric tons/yr). Total phosphorus loading from all sources averaged 430 metric tons/yr over the period of record (**Table 20**).

Next to rainfall, pump station S-5A represented the largest source of phosphorus loading to the WCAs (**Figure 34**). The S-5A pump station is located at the north end of WCA-1 and contributes approximately 18 percent (77 metric tons/yr) of the phosphorus load to the entire WCA system (**Table 20**). Pump station S-5A drains over 194 square miles of EAA agricultural land planted primarily in sugar cane and vegetables. Pump station S-8 represented the second largest single source of phosphorus loading to the WCA's contributing 16 percent or (67 metric tons/yr) of all phosphorus inflows over the period of record (**Figure 34**). Pump station S-8, located at the north end of WCA-3A on the Miami Canal, drains approximately 177 square miles of agricultural land planted primarily in sugarcane. Pump stations S-6 and S-7 each contribute 6 percent (28 metric tons) of all inflows. Pump station S-6 drains approximately 132 square miles of EAA land cultivated primarily for sugarcane and winter vegetables and discharges these surface waters into the Hillsboro canal and western WCA-1 marsh. Pump stations S-7 drains an area of over 131 square miles of EAA land cultivated primarily for sugar cane and sod farming. Water control structure L-3 contributes about 23 metric tons or 5 percent of all phosphorus inflows into the WCAs and tie as the fourth largest sources of nutrients discharged into the WCAs (**Figure 34**)

The L-3 canal drains a large agricultural area located within the western EAA. Land use within the L-3 basin includes citrus, cattle ranching and sugarcane grown on sandy soil. Pump station S-140, also located on the western border of WCA-

Figure 33. Major sources of total phosphorus inflows and outflows within the WCAs.

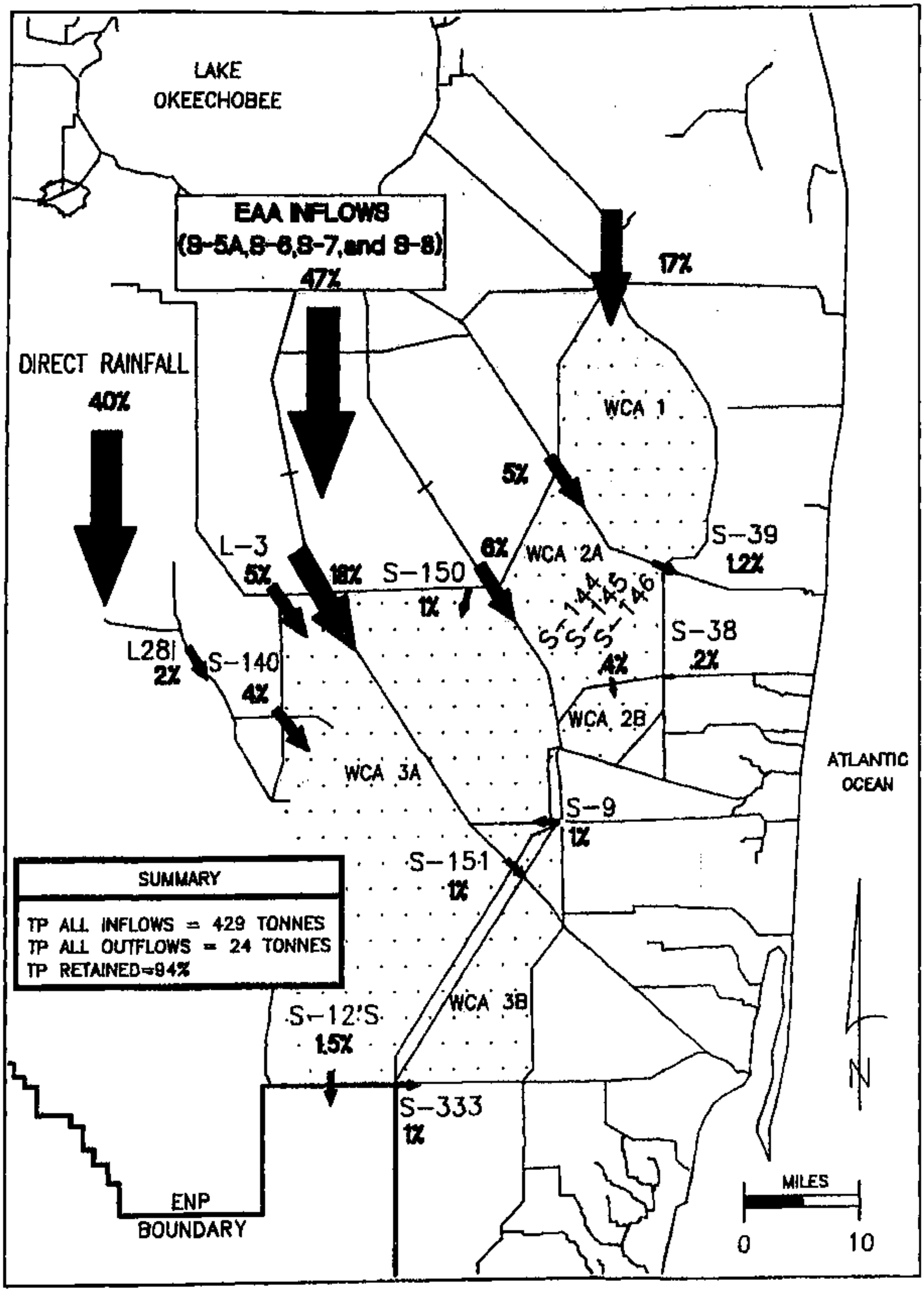


Table 20. Combined Water and Nutrient Budget for WCA-1, WCA-2A and WCA-3A. Average annual nutrient loadings and water volumes for water years 1979 - 1988.

INPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME**	PERCENT
S-5A	77*	18%	3,053	25%	.314	7%
S-8	67	16%	1,663	14%	.312	7%
S-6	28	6%	1,096	9%	.157	4%
S-7	28	6%	1,253	10%	.219	5%
L-3	23	5%	188	2%	.074	2%
S-140	18	4%	237	2%	.104	2%
L-28I	8	2%	131	1%	.071	2%
S-150	5	1%	197	2%	.057	1%
S-9	4	1%	338	3%	.136	3%
Rainfall	171	40%	4,027	33%	2.823	66%
Total input	**430**		**12,173**		**4.283**	
OUTPUT	**TOTAL PHOSPHORUS**	**PERCENT**	**TOTAL NITROGEN**	**PERCENT**	**VOLUME**	**PERCENT**
S-151	5.3	22%	430	18%	.183	4%
S-12A	0.8	3%	140	6%	.080	2%
S-12B	0.8	3%	130	6%	.075	2%
S-12C	2.3	10%	330	14%	.161	4%
S-12D	2.5	10%	400	17%	.168	4%
S-333	4.4	18%	330	14%	.139	3%
S-38	0.9	4%	110	5%	.043	1%
S-39	5.5	22%	230	10%	.078	2%
S-144.	0.7	3%	100	4%	.036,	1%
S-145	0.6	3%	100	4%	.039	1%
S-146	0.5	2%	80	3%	.030	1%
E.T.					3.331	76%
Total output	**24.3**		**2,380**		**4.362**	
Storage change	0.01		1		.00049	
Other sinks	405.6		9,784		-0.096	
Areal loading@	0.21		5.98			
Areal retention@	0.20		4.80			
& retention		94%		80%		
Residence time					0.86 (years)	

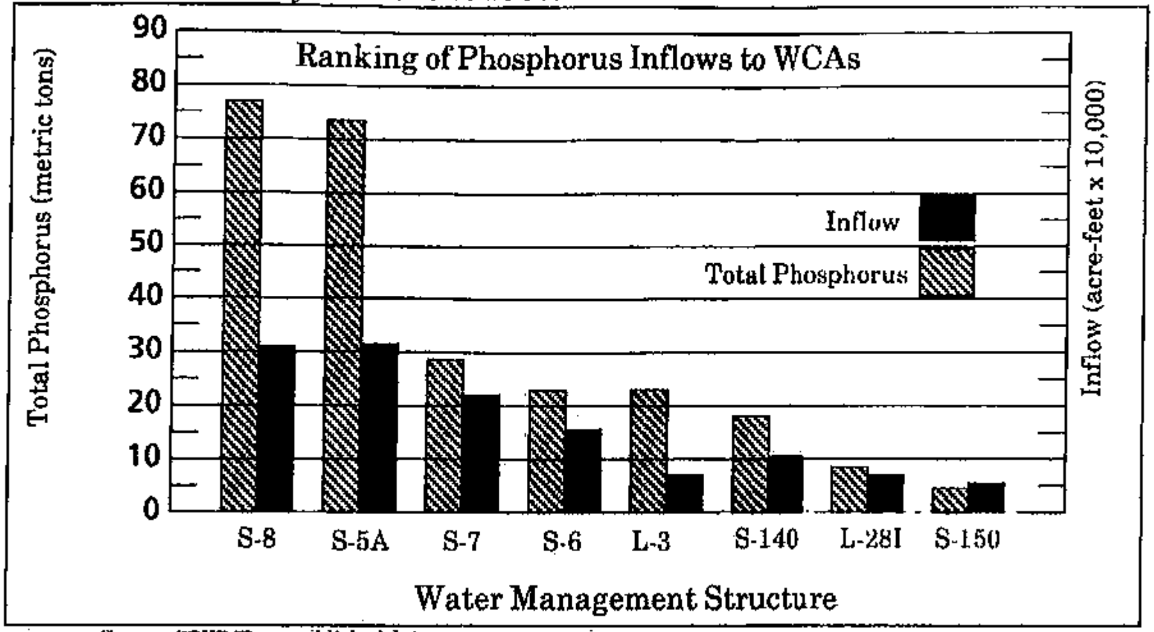
* = all loads reported in metric tons; ** = Volume in million acre feet; @ = grams/m^2/yr
Percents may not equal 100 due to rounding off error; Source: SFWMD, unpublished data

Table 21. Comparison of Total Phosphorus Loadings, Average Flow Weighted Nutrient Concentrations, and Water Inflow into the WCAs for water years 1979 - 1988

Major Inflow Structure	Ave. Annual inflow (Acre ft)	Ave.Flow weighted Total P conc. (mg/l)	Ave. Total P load (metric tons/yr)
S-5A	314,198	0.198	77
S-8	311,996	0.175	67
S-6	157,471	0.144	28
S-7	219,463	0.101	28
L-3	73,935	0.251	23
S-140	104,373	0.140	18
l-28I	71,497	0.095	8
S-150	56,741	0.075	5
Rainfall	2,823,401	0.049	172

SFWMD, unpublished data

Figure 34. Rankings of Average Annual Total Phosphorus Loadings to the WCAs at Eight Major Water Inflow Points (excluding rainfall) for water years 1979 to 1988.



Source; SFWMD, unpublished data

3A, drains a large area of wetlands and unimproved pasture and accounts for approximately 4 percent (18 metric tons/yr) of the phosphorus load discharged to the WCAs. Detailed water quality information concerning the sources of these high phosphorus loadings at S-140 and within the L-3 canal are not currently available but are thought to be the result of agricultural operations (cattle ranching, citrus, and sugar cane grown on sandy soils) in the northwest portion of the Everglades SWIM study area.

As a whole, the three WCA's retained approximately 95 percent of the phosphorus introduced into the system over the period of record (**Table 20**) and is comparable to Waller's (1975) estimate of 94 percent phosphorus retention calculated for the WCAs. This high retention rate indicates that the WCAs are highly efficient in assimilating the phosphorus loads introduced into these wetlands. On the average, 2.6 percent (11 metric tons/yr) of the phosphorus load introduced into WCA's were discharged into Everglades National Park through the S-12's and S-333 over the period of record (**Table 20**). Other phosphorus losses from the system included discharges through S-39 (1 percent) into the Hillsboro canal and discharges through S-151 (1 percent) to the Miami Canal (**Figure 33**).

Flow-weighted Phosphorus Concentrations. **Figure 35** presents a summary of average flow-weighted total phosphorus concentrations at each of the primary water management structures that supply inflow water to the WCAs. Highest concentrations of total phosphorus recorded throughout the WCA system occurred within the L-3 canal (0.251 mg/l). However, due to its relatively low discharge, L-3 represented only 2 percent of the inflow water to WCA-3A. The L-3 canal discharges nutrient-enriched canal water into the extreme northwest corner of WCA-3A. **Table 22** provides a listing of the relative rankings of phosphorus concentration (highest to lowest) at the major water management structures identified in **Figure 35**.

Figure 35. Average flow-weighted Total Phosphorus concentrations at major inflow / outflow structures in the Everglades WCAs for water years 1979-1988.

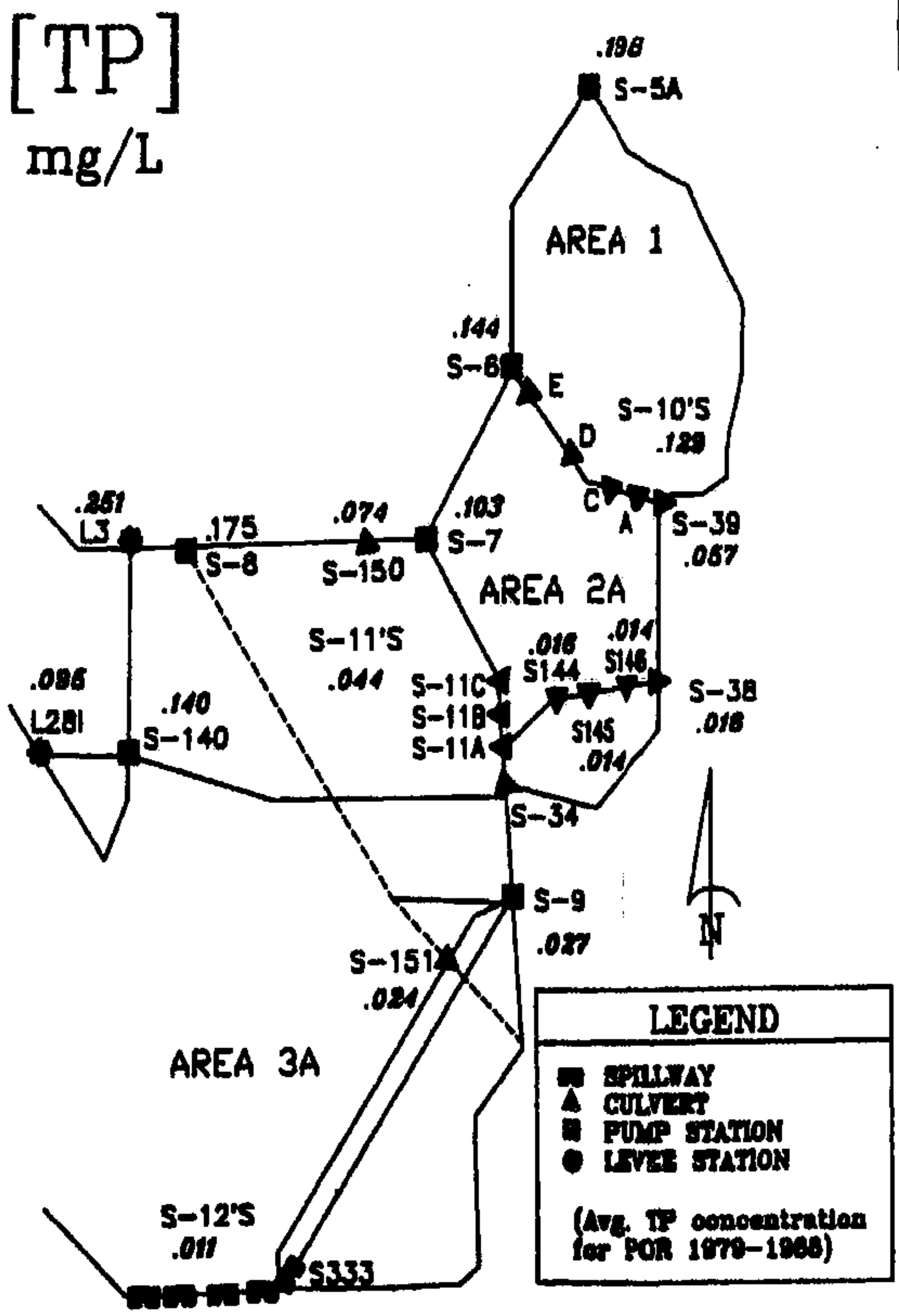


Table 22. Rankings of Flow-Weighted Phosphorus Concentrations at Major Inflows/Outflows to the WCAs for water years 1979 - 1988.

Rankings	Water Management Structure	Flow-weighted Phosphorus Concentration (mg/l)
1	L-3	0.251
2	S-5A	0.198
3	S-8	0.175
4	S-6	0.144
5	S-140	0.140
6	S-10's	0.129
7	S-7	0.101
8	L-28 I	0.095
9	S-150	0.075
10	S-39	0.057
11	S-11's	0.044
12	S-9	0.027
13	S-151	0.024
14	S-144	0.022
15	S-12's	0.011

Source: SFWMD,unpublished data

Total phosphorus concentrations at pump station S-5A ranked as the second highest (0.198 mg/l) recorded in the WCAs. Pump station S-5A supplies approximately 30 percent of the water to WCA-1. High phosphorus and nitrogen concentrations within these surface waters are a result of drainage of the EAA located north and west of WCA-1.

Pump station S-8, located on the northern levee of WCA-3A, produced the third highest value with an average flow-weighted total phosphorus concentration of 0.175 mg/l recorded. The S-8 pump station represents 10 percent of the inflow water to WCA-3A and currently drains a large area of land planted primarily in sugar cane.

High values identified in **Table 22** and **Figure 35** occurred at pump stations S-6 (0.144 mg/l) and S-7 (0.101 mg/l) ranked fourth and seventh respectively. As canal waters passed through WCA-3A, nutrient concentrations were considerably reduced with pump station S-151 recording an average concentration of 0.024 mg/l. Pump Station S-9, which drains largely urban lands in western Broward County exhibited a mean flow-weighted phosphorus concentration of 0.027 mg/l over the period of record.

Pump station S-140 (WCA-3A) and the four S-10 structures (WCA-2A) ranked fifth and sith with flow-weighted total phosphorus concentrations of 0.140 and 0.129 mg/l, respectively, recorded. In general, waters draining the EAA contained an average flow-weighted total phosphorus concentration of 0.149 mg/l. This value was calculated by averaging phosphorus concentration data collected over the period of record from the four major pump stations (S-5A, S-6, S-7 and S-8) which together drain the EAA (**Figure 35**).

The lowest average flow-weighted phosphorus levels identified in **Figure 35** occurred at the four S-12 structures (S-12A, S-12B, S-12C, S-12D), which discharge water from WCA-3A into ENP. Average Flow-weighted phosphorus concentrations at the S-12's were 0.011 mg/l over the ten year period of record.

WCA-1 Nutrient Budget. Direct rainfall represents the largest source of water for WCA-1, accounting for more than half (55 percent or 0.58 million acre-feet) of all inflows (**Table 23**). Pump station S-5A, located at the north end of the refuge, accounts for 30 percent (0.31 million acre-feet) of the surface water inflows into WCA-1, while pump station S-6, located on refuge's western boundary, contributes about 15 percent (0.16 million acre-feet). Two privately maintained pump stations (Acme Improvement District) deliver runoff from residential and urban land use sources but comprise less than 1 percent of WCA-1 inflow water. Over half (58 percent or 0.62 million acre-feet) of the water entering WCA-1 is lost as evapotranspiration. The next largest loss of water from WCA-1 are through the four S-10 structures located at the south end of the refuge which account for 35 percent (0.37 million acre-feet) of the outflow. Discharges from S-39 represent 7 percent (0.08 million acre-feet) of the water lost from WCA-1 to the Hillsboro canal (**Table 23**).

Annual average total phosphorus loadings for WCA-1 from all combined sources (rainfall + S-5A + S-6) averaged 137 metric tons for the 10 year period of record (**Table 23**). Maximum phosphorus loadings occurred during 1982-1984

Table 23. Nutrient and Water Budget for WCA-1 (1979- 1988). Average annual nutrient loadings and water volumes for water years 1979-1988.

INPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME**	PERCENT
S-5A	77*	56%	3,053	62%	.314	30%
S-6	28	20%	1,086	22%	.157	15%
Rainfall	33	24%	780	15%	.576	55%
Total input	**138**		**4,919**		**1.048**	
OUTPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME	PERCENT
S-39	5	8%	230	11%	.078	7%
S-10A	8	12%	284	14%	.084	8%
S-10C	16	24%	545	27%	.103	10%
S-10D	30	46%	800	39%	.138	13%
S-10E	6	10%	185	9%	.047	4%
E.T.					.619	58%
Total output	**65**		**2,044**		**1.086**	
Storage change	-0.46		-34		-9,230	
Other sinks	72.94		2,841		-47,222	
Areal loading@	0.23		8.37			
Areal retention@	0.12		4.83			
% retention		53%		58%		
Residence time					0.36 (years)	

* = all loads in metric tons; ** = Volume in million acre feet; @ = grams / m^2 yr
Percents may not equal 100 due to rounding off error; Source: SFWMD, unpublished data

following the 1981 drought (one of the worst droughts on record). Phosphorus loadings to WCA-1 increased 1.6 times during this period with a maximum annual phosphorus loading value of 201 metric tons recorded in 1984. Total nitrogen loadings for all combined sources averaged 4,919 metric tons/yr over the 10 year period with highest loadings recorded in 1988 (6,165 metric tons) (**Tables 23 and 24**).

Due to the low concentrations of nutrients found in bulk rainfall, direct precipitation contributed proportionally less of the total amount of nitrogen and phosphorus inflows (15 and 24 percent, respectively) to WCA-1 on an annual basis (**Table 23**). This is in sharp contrast to pump stations S-5A and S-6 which combined,

Table 24. Total Phosphorus and Total Nitrogen Loading, Water Inflows, and Water Residence Times for WCA-1, 1979 -1988.

Year	Total P loading (Metric Tons)	Total N loading (Metric Tons)	Inflows (Million ac-ft)*	Residence times (years)
1979	108	4,252	0.994	0.55
1980	123	5,526	1.063	0.35
1981	98	3,684	0.730	0.45
1982	170	5,547	1.120	0.31
1983	177	5,162	1.265	0.32
1984	201	5,641	1.179	0.37
1985	124	4,417	0.986	0.43
1986	139	5,877	1.326	0.38
1987	71	2,729	0.739	1.16
1988	177	6,165	1.160	0.31

* inflow includes S-5A, S-6 + rainfall; Source: SFWMD, unpublished data

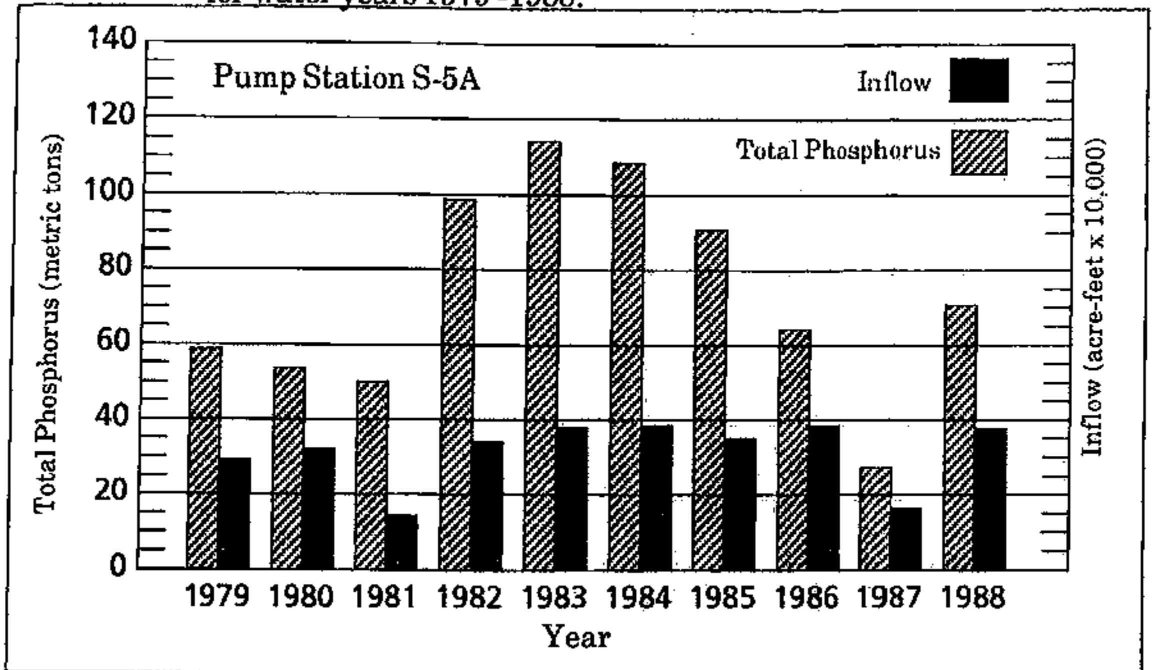
accounted for 76 percent of the phosphorus load (105 metric tons), 84 percent (4,140 metric tons) of the nitrogen load, within only 45 percent of the water entering the refuge **(Table 23)**. In comparison, rainfall contributed 24 percent (33 metric tons/yr) of the phosphorus load and 15 percent (780 metric tons/yr) of the nitrogen load within 55 percent of the inflow water. Pump stations S-5A and S-6 combined, drain over 329 square miles of agricultural land (sugar cane and winter vegetables) in western Palm Beach County. Over the past decade, surface water runoff from these two basins have historically contained high concentrations of nutrients, dissolved minerals and other contaminants (Lutz, 1977a, b; Dickson *et al.*, 1978, CH_2M-Hill, 1978).

Pump station S-5A ranks as the largest source of surface water nutrient inflow into WCA-1 accounting for 56 percent (77 metric tons) of the phosphorus, and 62 percent (3,053 metric tons) of nitrogen loading, while only representing 30 percent of the inflow water **(Table 23)**. Pump station S-5A drains approximately 194 square miles of agricultural land planted primarily in sugar cane and winter vegetable crops. The ten year period of record indicates that phosphorus loadings through S-5A increased substantially during a series of wet years (1982-1984) following the 1981 drought **(Figure 36)**.

Calculation of a total phosphorus areal loading rate (grams P/m^2/year) provides a standard measure of comparison for evaluating nutrient inflows into water bodies of different sizes. This calculation was used to compare nutrient loading rates among the three WCA's. Areal nutrient loading rates were calculated by summing all inflows discharged into the water body for a given year and dividing by the total surface area using appropriate conversion units (See **Appendix B** for details). Although the above calculation is useful for comparing phosphorus loading rates among different ecosystems, it does not adequately represent the manner in which nutrients are distributed within WCA-1 or WCA-2A. Areas of the marsh located downstream from water management inflow structures probably experience higher total phosphorus areal loading rates as compared to sites located within the interior marsh.

Calculation of a total phosphorus areal retention rate (grams P retained/m^2/yr.) provides a comparison of the amount of phosphorus annually retained within a water body on a uniform per square meter basis. Areal total

Figure 36. Total Phosphorus Loading and Discharges through S-5A to WCA-1 for water years 1979 -1988.



Source:SFWMD,unpublished data

phosphorus retention rates were calculated by subtracting the total phosphorus loadings at all inflows from the total phosphorus loadings at all outflows. The remainder represents the amount of phosphorus retained within the marsh and was termed "other sinks" which include phosphorus retained by marsh sediments, periphyton and macrovegetation and phosphorus lost to the atmosphere as ash, or taken up by some other phosphorus sink. The "other sinks" term was then divided by the surface area of each WCA using appropriate conversion factors (see **Appendix B** for details).

Areal loading rates for total phosphorus averaged 0.23 g/m^2/yr for WCA-1 (**Table 25**). Annual variations in total phosphorus areal loading rates for WCA-1 ranged from 0.12 grams P/m^2/yr (1987) to 0.34 grams P/m^2/yr observed in 1984 (**Table 26**). Areal loading rates for total phosphorus and total nitrogen were found to be significantly correlated, reinforcing the fact that both nutrients are derived from a common source.

Areal nutrient loading rates calculated for each of the WCAs were contrasted with areal nutrient loading rates for nitrogen and phosphorus from Lake Okeechobee in **Table 26.** These data indicate that current total phosphorus loading rates within

Table 25. Comparison of Areal Nutrient Loading Rates for the Everglades Water Conservation Areas and Lake Okeechobee.

Loading rate (grams/m^2/yr)	WCA-1	WCA-2A	WCA-3A	Lake Okeechobee
Total Nitrogen	8.37	8.11	3.48	2.64
Total Phosphorus	0.23	0.25	0.13	0.28

Source: SFWMD, 1989, unpublished data, WCA data POR 1979-1988; Lake Okeechobee data from Federico *et al.*, 1981.

WCA-1 and WCA-2A are similar to those of Lake Okeechobee while areal total nitrogen loading rates are more than triple those of the lake (Table 25). This information indicates that current WCA areal nutrient loading rates are comparable to those of a nutrient-enriched eutrophic lake (Lake Okeechobee). These comparisons are important in light of the fact that the Everglades ecosystem and its unique vegetation communities have evolved over the past 4,500 years within a largely phosphorus-limited (oligotrophic) environment.

WCA-1 displayed an average annual total phosphorus areal retention rate of 0.12 grams/m^2/yr (Table 23). The highest total phosphorus areal retention rate observed over the period of record was 0.21 grams/m^2/yr (1984), and the lowest rate observed was 0.09 grams/m^2/yr recorded in years 1981 and 1987. Annual variations in the percentage of total phosphorus retained within WCA-1 are shown in Table 26. The highest percent retention of phosphorus (77 percent) occurred in 1987 and lowest

Table 26. Total Phosphorus Areal Loading rates, Areal Retention rates and Percent Retention for WCA-1 for water years 1979 -1988.

Year	Areal Loading Rates for Total P*	Areal P Retention rates*	Percent Phosphorus Retention
1979	0.18	0.14	75%
1980	0.21	0.10	46%
1981	0.17	0.09	56%
1982	0.29	0.12	40%
1983	0.30	0.14	45%
1984	0.34	0.21	62%
1985	0.21	0.14	66%
1986	0.24	0.13	55%
1987	0.12	0.09	77%
1988	0.30	0.18	60%

Source: SFWMD, unpublished data *Grams per square meter per year

retention (40 percent) occurred in 1982. Mean total phosphorus retention for the period of record was 53 percent (Table 23).

Calculation of water residence time for each WCA provides a useful index of the length of time (in years) that it takes to replace the mean annual storage volume of each WCA. Water residence times indicate the time that water remains within a specific WCA before being discharged or lost from the system as evapotranspiration or seepage. This parameter also provides an index of the amount of contact time that nutrients have to interact with marsh sediments or plant vegetation. Water residence times for WCA-1 averaged 0.36 years over the 10 year period of record with values ranging from 0.31 years in 1982 and 1988 to 1.16 years in 1987 (Table 24).

WCA-2A Nutrient Budget. In contrast to WCA-1 and WCA-3A which receive the majority of their source water from direct rainfall, WCA-2A receives the majority of its water (59 percent) from surface water inflows which includes drainage from EAA lands and outflows from WCA-1. Rainfall accounted for only 41 percent of the inflow to WCA-2A over the period of record, while the four S-10 discharge structures (S-10A, S-10C, S-10D, and S-10E) and S-7 pump station represented 37 and 22 percent, respectively, of the source water inflows into the WCA-2A marsh (Table 27).

Forty-two percent of the water lost from WCA-2A is due to evapotranspiration (**Table 27**). The S-11 control structures (S-11A, S-11B and S-11C) account for 45 percent of the water leaving the marsh. Other water losses include discharges through S-38 (4 percent) and discharges to WCA-2B through S-144, S-145 and S-146 (9 percent) as shown in **Table 27**.

Table 27. Nutrient and Water Budget for WCA-2A. Average annual nitrogen and phosphorus loadings and water volumes for water years 1979-1988.

INPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME**	PERCENT
S-7	28*	25%	1,253	34%	.219	22%
S-10A	8	7%	284	8%	.084	8%
S-10C	16	14%	645	15%	.103	10%
S-10D	30	27%	800	22%	.138	14%
S-10E	6	6%	185	5%	.047	5%
Rainfall	25	22%	569	16%	.412	41%
Total input	**112**		**3,639**		**1.002**	
OUTPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME	PERCENT
S-38	0.9	3%	111	5%	.043	4%
S-144	0.7	2%	102	5%	.036	3%
S-145	0.7	2%	102	5%	.039	3%
S-146	0.5	1%	79	4%	.030	3%
S-11A	4.5	14%	480	23%	.174	15%
S-11B	10.9	35%	577	28%	.180	15%
S-11C	13.3	42%	636	30%	.179	15%
E.T.					.485	42%
Total output	**31.3**		**2,087**		**1.166**	
Storage change	-0.76		-56		-14,000	
Other sinks	79.63		1,493		-177,789	
Areal loading@	0.25		8.11			
Areal retention@	0.18		3.33			
% retention		71%		41%		
Residence time					0.20 (years)	

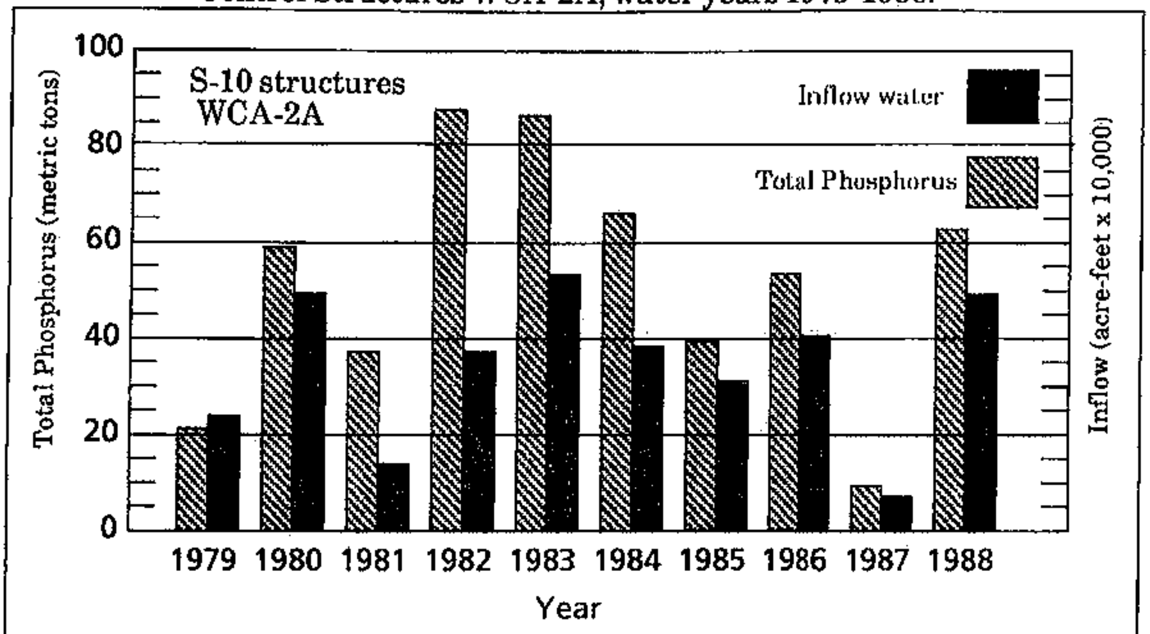
* = all loads reported in metric tons ; ** = Volume in million acre feet; @ = grams / m²/yr
Percents may not equal 100 due to rounding off error; Source: SFWMD, unpublished data

Unlike WCA-1, which contains an interior perimeter canal that entirely encircles the marsh, phosphorus-enriched canal waters that are discharged into this sawgrass marsh move directly across WCA-2A as sheet flow resulting from discharges from the four S-10 water control structures. These four water control structures represent the largest source of nutrients imported into WCA-2A accounting for over 52 percent of the phosphorus load (60 metric tons) and 50 percent of the nitrogen load (1,841 metric tons) introduced into the marsh over the period of record (**Table 27**). Nutrients contained in direct rainfall account for only 22 and 16 percent of the phosphorus and nitrogen loads, respectively, to WCA-2A.

Pump station S-7 represents the third major source of nutrient inflow into WCA-2A accounting for 25 percent of the phosphorus load (28 metric tons) and 34 percent of the nitrogen load (1,253 metric tons) into the western portion of WCA-2A (**Table 27**). Some of this nutrient-enriched water penetrates the marsh within the vicinity of the S-7 discharge structure and downstream along the L-38 canal. However, the majority of this water is routed south to the S-11 structures into WCA-3A through the L-38 Canal and has relatively little impact on water quality east of the canal. Although S-7 discharges have little effect on water quality in WCA-2A, these nutrient-enriched inflows represent an important source of phosphorus loading to the northeastern sector of WCA-3A.

A comparison of annual phosphorus loadings into the northern WCA-2A marsh through the S-10 structures for the ten year period of record is provided in **Figure 37.** Phosphorus loadings from the S-10s increased markedly during 1982 and 1983 following the 1981 drought year. These increases may be a response to increased soil subsidence in the EAA resulting from the previous drought year followed closely by two wet years (1982 and 1983). Total phosphorus loading into WCA-2A showed a decreasing trend during 1987 with loadings increasing in 1988 (**Figure 37**).

Figure 37. Total Phosphorus Loading and Inflow through the Four S-10 Water Control Structures WCA-2A, water years 1979-1988.



Source: SFWMD, unpublished data

Average nutrient loadings for WCA-2A from all sources (rainfall + S-10s + S-7) for the period of record were 112 metric tons for total phosphorus and 3,639 metric tons for total nitrogen (**Table 27**). Peak years of phosphorus loading to WCA-2A from all sources occurred in 1982 with 159 metric tons recorded while nitrogen loading peaked in 1980 with 5,206 metric tons (**Table 28**).

Water residence times within WCA-2A varied widely over the ten year period of record, decreasing significantly from 1982 - 1986 (**Table 28**). A five-year drawdown of the marsh was initiated in 1980 to encourage the regrowth of tree island and wet prairie communities drowned out during previous high water years (Dineen, 1972; Worth, 1983, 1988). During the 1970's, WCA-2A served as a water storage area and maintained a water regulation schedule (13.0-14.5 NGVD) that allowed a great deal more water to be stored within WCA-2A than permitted under the drawdown regulation schedule (9.5 - 12.5 NGVD). Water residence times calculated for WCA-2A during years in which the the higher regulation schedule was in effect (1979-1980) ranged from 1/2 to 3/4 years in length. Implementation of the drawdown schedule in November 1980, coincided with the onset of the 1981 drought resulted in decreased water residence times ranging from one to two months (**Table 28**).

Table 28. Total Phosphorus, Total Nitrogen Loadings, Inflow Water Volume and Water Residence Times for WCA-2A, 1979-1988.

Year	Total P loading (Metric Tons)	Total N loading (Metric Tons)	Ave. Annual inflow (million Ac.-ft)	Water Residence times (years)
1979	58	2,307	0.797	0.72
1980	99	5,206	1.134	0.43
1981	82	1,988	0.632	0.22
1982	159	3,885	1.002	0.15
1983	139	4,248	1.314	0.15
1984	139	4,194	1.142	0.09
1985	85	2,998	0.921	0.08
1986	120	4,023	1.122	0.09
1987	52	1,619	0.587	0.25
1988	127	4,782	1.220	0.11

Source: SFWMD, unpublished data

Areal loadings rates for total phosphorus for WCA-2A averaged 0.25 grams/m^2/yr (**Table 27**) with a maximum value of 0.36 grams/m^2/yr recorded in 1982 and a minimum value of 0.12 grams/m^2/yr observed in 1987 (**Table 29**).

Table 29. Areal Loading Rates, Areal Retention Rates and Percent Retention for Total Phosphorus, WCA-2A for water years 1979-1988.

Year	Areal loading rates for Total P*	Areal retention rates Total P*	Percent retention Total P
1979	0.13	0.10	80%
1980	0.22	0.16	71%
1981	0.18	0.13	71%
1982	0.36	0.30	84%
1983	0.31	0.25	80%
1984	0.31	0.21	67%
1985	0.19	0.07	38%
1986	0.27	0.10	39%
1987	0.12	0.08	70%
1988	0.28	0.19	65%

Source: SFWMD, unpublished data * = grams per square meter per year

Annual variations in areal retention rates for total phosphorus are also shown in **Table 29**. The highest areal retention rate was 0.30 grams/m^2/yr observed in 1982 and the lowest retention rate was 0.08 grams/m^2/yr recorded in 1987. Average total phosphorus areal retention rates for the period of record for WCA-2A were 0.18 grams/m^2/yr (**Table 27**). The WCA-2A marsh averaged about 71 percent retention of phosphorus over the ten year period of record (**Table 27**). Highest percent retention occurred in 1982 (84 percent) while lowest retention rates (38 percent) occurred in 1985 (**Table 29**).

WCA-3A Nutrient Budget. Rainfall represents the largest source of inflow water to WCA-3A accounting for 59 percent (1.85 million acre ft.) of all inflows for the 786 sq. mi. (2,036 km^2) Everglades marsh (**Table 30**). The largest sources of surface water inflow into WCA-3A are the three S-11 structures (S-11A, S-11B, S-11C) which receive a mixture of inflow water from WCA-2A and the L-38 Canal, which serves as a drainage canal for the S-7 pump station. The S-11's account for 18 percent (0.53 million acre-feet) of the inflow water to WCA-3A, followed in order by pump station

S-8, at 10 percent (0.31 million acre-feet), L-3 (2 percent), pump station S-9 (4 percent), pump station S-140 (3 percent), the L-28 interceptor canal (2 percent), and S-150 (2 percent) (**Table 30**). Direct surface water inflows draining the EAA account for about 15 percent of all inflows into WCA-3A (not counting the S-11's and rainfall). These data indicate that the EAA represents an important source of inflow water for WCA-3A. Surface waters draining these lands are highly mineralized and contain high concentrations of phosphorus and nitrogen (Waller and Earle, 1975; McPherson *et al.*, 1976).

Due to vast size of WCA-3A, nearly three quarters (2.23 million acre-feet) of the water entering the marsh is lost from the system as evapotranspiration. The S-12 structures (S-12A, S-12B, S-12C and S-12D) located at the extreme southern border of WCA-3A, discharged about 15 percent (0.48 million acre-feet) of WCA-3A's water budget into Everglades National Park over the ten year period of record, while S-333 delivered another 5 percent (0.14 million acre-feet). Water control structure S-151 accounted for another 6 percent (0.18 million acre-feet) of the water lost from the system (**Table 30**).

Table 30. Nutrient and Water Budget for WCA-3A. Average annual phosphorus and nitrogen loadings and water volume for water years 1979-1988.

INPUT	TOTAL PHOSPHORUS	PERCENT	TOTAL NITROGEN	PERCENT	VOLUME**	PERCENT
S-8	67*	25%	1,663	23%	.312	10%
L-3***	23	9%	188	3%	.074	2%
S-140	18	7%	237	3%	.104	3%
S-11C	13	5%	636	9%	.179	6%
S-11B	11	4%	577	8%	.180	6%
S-11A	5	2%	480	7%	.174	6%
L-28I	8	3%	131	2%	.071	2%
S-150	5	2%	197	3%	.057	2%
S-9	4	2%	338	5%	.136	4%
Rainfall	114	43%	2,634	37%	1.851	59%
Total Input	**269**		**7,081**		**3.138**	
OUTPUT	**TOTAL PHOSPHORUS**	**PERCENT**	**TOTAL NITROGEN**	**PERCENT**	**VOLUME**	**PERCENT**
S-151	5.3	33%	428	24%	.182	6%
S-12A	0.8	5%	143	8%	.080	3%
S-12B	0.8	5%	133	7%	.075	2%
S-12C	2.4	14%	332	19%	.160	5%
S-12D	2.5	15%	395	22%	.168	6%
S-333	4.4	27%	333	19%	.139	5%
E.T.					2.227	73%
Total Output	**16**		**1,763**		**3.031**	
Storage change	0.01		1		.00049	
Other sinks	253		5,317		.106	
Areal loading@	0.13		3.48			
Areal retention@	0.12		2.61			
% retention		94%		75%		
Residence time					0.73 (years)	

* = all loads reported in metric tons ; ** = Volume in million acre feet; @ = grams / m²/yr;
*** = L-3 inflows based on a flow distribution of 75% inflow into the N.W. corner of WCA-3A, POR 1977-1988; Percents may not equal 100 due to round off error; Source: SFWMD, unpublished data.

Although rainfall contributes over 59 percent of the inflow water, surface water inflows from outside WCA-3A account for the largest source of nutrient inflows into the marsh. Combined surface water inflows from all sources (the S-11's, S-8, S-9, S-140, S-150, L-28 interceptor canal, and L-3) for the period of record contribute an average of 57 percent (155 metric tons) of the phosphorus and 63 percent (4,447 metric tons) of the nitrogen inflow into WCA-3A (**Table 30**).

Annual nutrient loadings from all combined sources (rainfall + S-11's, S-8, S-9, L-3, S-150 and the L-28 interceptor canal) averaged 269 metric tons for total phosphorus and 7,081 metric tons for nitrogen for the period of record. Years of peak phosphorus loading occurred in 1982 with 503 metric tons/yr recorded (**Table 31**). Phosphorus loading to the WCA-3A marsh increased threefold following the 1981 drought. Phosphorus loadings to WCA-3A remained high for a period of 5 years (1982-1986). Lowest phosphorus loading (159 metric tons/yr) occurred in 1980. Rainfall accounted for 43 percent (114 metric tons) of the phosphorus entering the WCA-3A over the period of record (**Table 30**).

By far, the largest single source of nutrient inflow into WCA-3A was pump station S-8, located on the Miami Canal (C-123) at the north end of WCA-3A. Over the period of record, S-8 contributed an average of 67 metric tons of phosphorus into WCA-3A representing 25 percent of all phosphorus inflows and 23 percent (1,663 metric tons) of the nitrogen inflow (**Table 30**). Annual variations in discharge and phosphorus loadings at pump station S-8 are shown in **Figure 38**.

Table 31. Total Phosphorus and Total Nitrogen loadings , Inflow Water and Water Residence Times for WCA-3A, water years 1979 - 1988.

Year	Total P Loading (Metric Tons)	Total N Loading (Metric Tons)	Inflow (Million Acre-feet)	Water Residence Time (Year)
1979	184	5,684	2.853	1.15
1980	159	7,708	2.988	0.90
1981	195	5,242	2.456	1.09
1982	503	8,594	3.639	0.50
1983	287	7,339	3.923	0.52
1984	288	6,392	3.018	0.60
1985	251	6,521	3.059	0.47
1986	389	9,681	3.721	0.72
1987	181	4,778	2.441	1.35
1988	282	8,489	3.596	0.82

Source: SFWMD, unpublished data

Annual phosphorus loadings to WCA-3A though S-8 increased markedly during 1982 and 1986 in response to antecedent drought years (1981 and 1985). Highest phosphorus loadings occurred in 1986 (171 metric tons) and 1982 (162 metric tons). Lowest phosphorus loadings through S-8 occurred in 1981 with only 17 metric tons reported (**Figure 38**). These data suggest that that phosphorus (and nitrogen) loading through S-8 are associated with regional drought cycles, with highest loading rates occurring immediately following a major drought event. Increases in surface water phosphorus loads to the WCAs following a drought may be due to increased soil subsidence within the EAA and the Everglades.

The average annual phosphorus loading rate (0.13 grams/m^2/yr) calculated for WCA-3A was about one half that of WCA-1 or WCA-2A (**Table 25**). Although WCA-3A receives more than twice as much phosphorus and nitrogen compared to the other two WCAs, its large size (786 sq. mi.) minimizes the overall impact of introduced nutrients in terms of a generalized phosphorus loading rate. The highest total

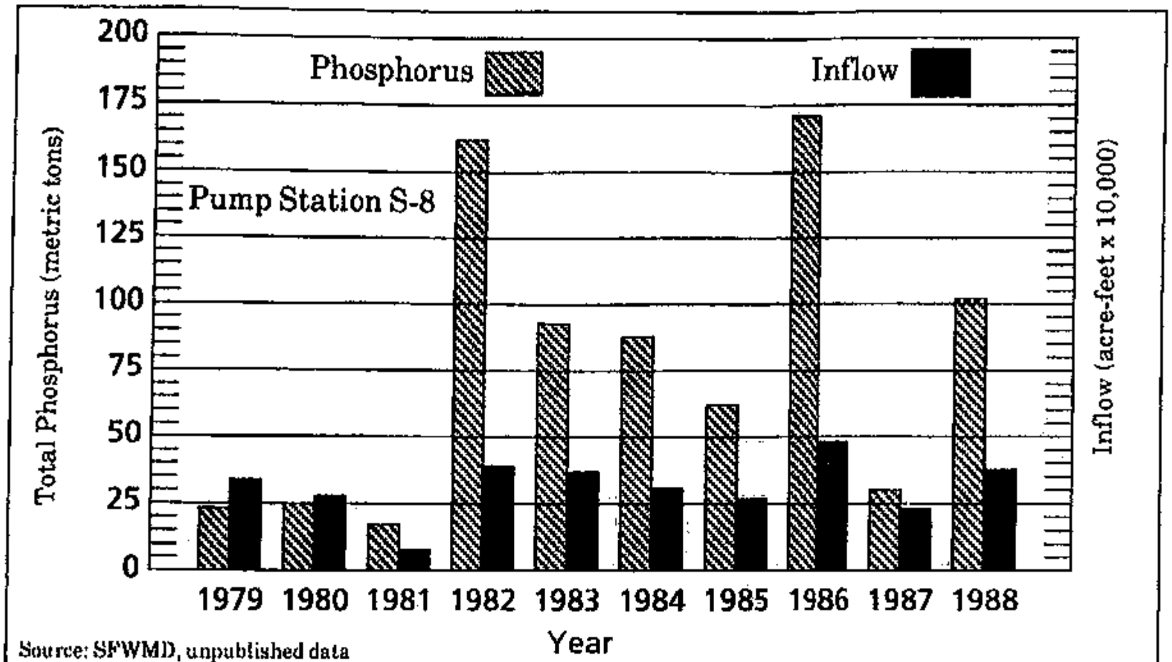


Figure 38. Total Phosphorus Loading and Discharges through S-8, WCA-3A, water years 1979-1988.

Table 32. Comparison of Marsh Surface Area, Total Phosphorus Loading and Areal Loading Rates, Percent Retention and Water Residence Times Among the Three Water Conservation Areas, 1979-1988.

Water Management Unit	Size of WCA's Sq. Mi. (km²)	Ave. Total P Loading *	Areal Total P Loading Rate **	Total P % Retention	Ave. Water Residence Time (year)
WCA-1	227 (588)	138	0.23	59%	0.36
WCA-2A	173 (448)	112	0.25	71%	0.20
WCA-3A	786 (2,036)	267	0.13	94%	0.73

Source: SFWMD, unpublished data, * = metric tons/yr, ** = Grams/m²/yr

phosphorus loading rate for WCA-3A occurred in 1982 (0.25 grams/m²/yr), while the lowest value (0.08 grams/m²/yr) occurred during 1980 (**Table 33**).

Annual total phosphorus retention rates averaged 0.12 grams/m²/yr over the period of record (**Table 30**) with highest retention rates recorded in 1982 (0.25 grams/m²/yr) and lowest values (0.07 grams/m²/yr.) observed in 1980. These data translate into an average phosphorus retention of 94 percent for WCA-3A, the highest phosphorus retention of the three WCA's (**Table 32**). Highest phosphorus retention occurred in 1982 (97 percent), while lowest values occurred in 1985 (86 percent) (**Table 33**). Overall, these data indicate that WCA-3A is highly efficient in removing phosphorus introduced into the marsh.

Calculations of water residence times (**Table 32**) indicated that WCA-3A had the longest average water residence time of all three WCA's (0.73 years). This value indicated that water remained in WCA-3A approximately 2-3 times longer than

Table 33. Areal loading, Areal Retention Rates and Percent Retention for Total Phosphorus for WCA-3A, water years 1979 - 1988.

Year	Areal Total P Loading Rates*	Areal Total P Retention Rate*	% Phosphorus Retention
1979	0.09	0.09	95%
1980	0.08	0.07	92%
1981	0.10	0.09	96%
1982	0.25	0.24	97%
1983	0.14	0.13	94%
1984	0.14	0.13	92%
1985	0.12	0.11	86%
1986	0.19	0.18	94%
1987	0.09	0.08	92%
1988	0.14	0.13	92%

Source: SFWMD, unpublished data, * =grams/m²/yr

WCA-1 or WCA-2A and may be in part (along with the large surface area of WCA-3A) responsible for the high phosphorus retention (94 percent) observed within WCA-3A over the period of record. These data reinforce the general principle that longer water residence times within a given WCA permit greater uptake of nutrients by sediments and aquatic vegetation.

Impacts of the IAP on Water Quality. Over the past decade, drainage of the EAA has generated approximately 1 million acre-feet of surface water runoff per year (**Table 20**) from agricultural lands located south of Lake Okeechobee. The majority of runoff occurs from June to October (wet season). Prior to 1979, a significant portion of EAA runoff was either pumped north to Lake Okeechobee through the S-2 and S-3 pump stations, or routed south to the WCAs through pump station S-6, S-7 or S-8.

Until the summer of 1979, the routing of water north or south from the EAA depended on water levels and water storage conditions in Lake Okeechobee and the WCAs as well as rainfall conditions over South Florida. The Interim Action Plan (IAP) rerouted these historical flows south to the WCAs to comply with DER operating permit criteria for the discharge of these waters into Lake Okeechobee through pump stations S-2 and S-3. The best available information (**Table 34**) indicates that the IAP has resulted in a 10 percent (45.4 metric tons/yr) increase in phosphorus load discharged to the WCAs through pump stations S-6, S-7 and S-8 since implementation of the plan in 1979. This estimate is based on a comparison between actual phosphorus loadings recorded from pump stations S-2 and S-3 from 1979 - 1987 (IAP in effect), with phosphorus loadings generated from a computer simulation model (South Florida Regional Routing Model, Trimble, 1986) which estimated phosphorus loading from both pump stations based on District pumping criteria in effect prior to implementation of the IAP (**Table 34**). The model simulation indicated that without the IAP in effect, pump stations S-2 and S-3 pumped 57.9 metric tons of phosphorus into Lake Okeechobee on an annual average basis. Comparison of actual discharges through both pump stations while the IAP was actually in effect indicated that only 12.5 metric tons/yr of phosphorus were discharged to the lake (analyses did not include emergency backpumping for water supply). The difference between actual and simulated phosphorus loadings through S-2 and S-3 is 45.4 metric tons/yr (**Table 34**). It is assumed that this additional 45.4 metric tons of phosphorus has been rerouted south to the WCAs through pump

Table 34. Impact of the Interim Action plan (IAP) on Total Phosphorus Loadings Routed South to the WCAs based on Historical and Computer Simulated Loadings to Lake Okeechobee through Pump Stations S-2 and S-3 from 1979 -1987.

Water year	Flood Control Backpumping With IAP in Effect (Actual data)*		Flood Control Backpumping Without IAP in Effect (Model simulation**		Difference (Simulated minus actual)	
	S-2	S-3	S-2	S-3	S-2	S-3
1979	11.9@	4.4	21.5	12.1	9.6	7.7
1980	5.5	2.6	34.2	9.2	28.7	6.5
1981	0	0	28.1	7.0	28.1	7.0
1982	14.1	6.0	56.9	36.2	42.7	30.2
1983	11.4	15.1	40.5	55.6	29.0	40.5
1984	8.7	4.2	40.6	21.1	31.9	17.0
1985	12.5	11.1	35.0	24.0	22.5	13.0
1986	2.8	2.2	33.4	42.3	30.6	40.1
1987	0.1	0	13.3	10.6	13.2	10.6
Total	67.1	45.4	303.5	218.0	236.4	172.6
Average	7.5	5.0	33.7	24.2	26.3	19.2
Sum (S-2+S-3)	12.5		57.9		45.4***	

* = Recorded Inflows into Lake Okeechobee minus backpumping for flood control or water supply under declared emergency conditions.
** = Computer Model Run using South Florida Regional Routing Model (Trimble, 1986)
*** = Additional total phosphorus loadings routed to WCAs.
@ = all values in metric tons as total phosphorus

stations S-6, S-7 and S-8 since implementation of the IAP. This increase represents about a tenth (10 percent) of current phosphorus loadings to the WCAs as compared to contributions from the EAA (47 percent) and bulk rainfall (40 percent).

Pesticide and Herbicide Monitoring in the WCAs. Pesticides selected for monitoring by the SFWMD were based on (a) the availability of a suitable analytical method, (b) potential for significant environmental impact, and (c) usage in the drainage basin. A total of 67 surface water samples, and 60 sediment samples were collected from August 1984 to July 1988 in the EAA (Pfeuffer, in prep.). Until 1987, sampling occurred biannually. Since then, sampling has been conducted on a quarterly basis. Pesticide water and sediment samples were taken at structures S-2, S-3, S-5A, S-6, S-7, S-8, and at the intersection of L-3 and L-4 canals. Of these samples, 14 surface water samples, (21 percent), and 22 sediment samples, (37 percent) had detectable pesticide residues. For the WCAs, a total of 21 surface water samples and 25 sediment samples were collected. Samples were taken at S-9, S-31, and S-12C. Of the samples taken, one (5 percent) surface water sample and five sediment samples (20 percent) had detectable pesticide residues. Out of a total of six surface water samples and five sediment samples collected in the western WCA basin, (one sample site at S-190), one surface water sample (17 percent) and one sediment sample (20 percent) had detectable pesticide residues (Pfeuffer, in prep.).

No seasonal trends could be determined from these limited data. Information as to which stations consistently recorded pesticide concentrations could be determined by ranking the stations on the basis of the percent of positive samples. In reviewing the rankings, caution should be used as some stations have been sampled as few as five times. Structure S-5A appears to be most frequently impacted by pesticide residues. Persistent compounds are most frequently detected in water and sediment samples at this location.

Atrazine and zinc phosphide were the only two compounds detected in surface water samples. Zinc phosphide is used for pest control, specifically for rats and other rodents, in sugar cane fields. This compound was detected during the first two special monitoring events, but not during subsequent quarterly sampling. Since zinc phosphide is acutely toxic, monitoring will continue during the routine sampling to determine any patterns and explanations for its presence.

The herbicide atrazine is used primarily on sugar cane and corn crops for weed control. It can also be used for non-crop purposes such as lawns and ornamentals. Atrazine can persist in the soil due to strong adsorption to organic matter. Contamination of water is more likely to be due to runoff. Atrazine was consistently detected in water samples, however, the levels found were not considered to have any potential adverse environmental or health effects as this compound does not bioaccumulate and is not considered very toxic. The majority of the 23 samples that contained detectable levels of atrazine had concentrations between 0.1 and 1.0 *u*g/l. Only 9 samples had levels greater than 1.0 *u*g/l, with the highest concentration being 12.3 *u*g/l. Stations S-5A, S-6, S-7, and S-8 had detectable quantities more than once, indicating that more of the compound is used within these drainage basins. In a survey done by the FDER in July 1987, surface water samples were collected from nine canal sites located around the perimeter of the three WCAs. These samples were analyzed for 67 compounds, with atrazine being the only pesticide detected (LOTAC, 1988). At present, no state or EPA guidelines exist for atrazine concentrations in drinking or surface water.

The majority of pesticide residues detected in sediments consisted of DDD and/or DDE. Both DDD and DDE are degradation products of DDT. In aquatic environments, both compounds bioaccumulate and can also be adsorbed to wet soils and biota. DDD, in addition to being a degradation product of DDT, was formerly used as an insecticide on fruits and vegetables. Both DDD and DDE can be lost from aquatic systems due to volatilization. The levels detected at the sampling sites were lower than those routinely found during previous SFWMD monitoring (Pfeuffer, 1985). These compounds were found consistently at the same stations (S-2, S-3, S-6, S-7, and S-5A). The DER study conducted in July 1987 revealed the presence of three pesticide compounds: 2,4,D, ametryne and methamiodophos. These compounds were found in the sediments samples taken at S-6, S-31, the L-3 oil well bridge, and Bridge 25 on U.S. 41 (Pfueffer, in prep.).

Other compounds detected in WCA canal sediments were diazinon, malathion, and chlorpyrifos, (organophophorus insecticides), ametryne, (a triazine herbicide compound), 2,4-D, (a phenoxy-aliphatic herbicide), methamiodophos, (an insecticide/acaricide), paraquat, (a non-selective herbicide, defoliant, desiccant, and plant growth regulator), heptachlor epoxide, (a degradation product of a chlorinated hydrocarbon insecticide), atrazine, and delta BHC, (a chlorinated hydrocarbon insecticide). These compounds were detected only once during a single sampling event. The sediment residues detected were not found in concentrations high enough to present potential adverse health or environmental effects.

6. Water Quality Degradation in the WCAs.

Impacts of Nutrient Enrichment on the Everglades Ecosystem. Analysis of the data presented in the previous section of this plan identifies the Everglades Agricultural Area (EAA) as the single most likely and largest source of nutrients discharged into the WCAs. Surface waters which drain these agricultural lands contain high concentrations of nitrogen, phosphorus, sulfates, chlorides, trace metals and occasional trace amounts of pesticides. The discharge of these surface water contaminants into the WCAs has lead to concerns that elevated nutrient levels are causing a variety of impacts to native Everglades flora, ranging from the microorganism to macrophyte level and may pose a threat to the base of the Everglades food web. High nutrient concentrations have also been shown to affect the dissolved oxygen regime of marsh surface waters. Surface water's entering WCA1 and passing through the S-5A and S-6 pumping stations contain nutrient levels that are causing imbalances in the natural populations of aquatic flora and fauna in violation of state water quality standards. This nutrient enrichment problem is also leading to significant alterations of Everglades vegetation which in turn is significantly altering or replacing native fish and wildlife habitat within WCA-2A and WCA-3A. These impacts appear to be on the increase and will continue to spread unless nutrient concentrations in these waters are reduced prior to their delivery to the WCAs.

Impacts on Everglades Periphyton. The Everglades contains a great abundance and diversity of different life forms, many which are large and familiar such as alligators and wood storks, sawgrass stands, wet prairies, aquatic sloughs and tree islands. However, hundreds of species are virtually invisible to the naked eye including "periphyton" which consist of millions of microscopic plants or algae that live below the water surface attached to plants or form floating mats on the water's surface. Periphyton probably represent an (a) important component of the Everglades food web (Hunt, 1953; Tabb *et al.*, 1967; Craighead, 1971; Carter *et al.*, 1973; Wood and Maynard, 1974; Browder, 1981; Pope *et al.*, 1980) and also play important roles in (b) marsh primary production (Hunt, 1961;Wood and Maynard, 1974; Wilson, 1974; Van Meter-Kasanov, 1973); (c) influencing diurnal surface water pH, dissolved oxygen and carbon dioxide concentrations through photosynthetic production and respiration (Hunt 1961, Wilson 1974, Belanger and Platko, 1986); (d) marl soil formation through calcium carbonate precipitation as a result of periphyton photosynthesis (Gleason, 1972; Gleason and Spackman, 1974); (e) providing feeding and microhabitat for the survival of the eggs of Everglades fish and invertebrates during the dry season (Harrington, 1959); and (f) calcareous periphyton communities may also play an important role in the uptake of nutrients by marsh vegetation (Gleason, 1974b; Swift and Nicholas, 1987).

The general response of these microorganisms to nutrient enrichment is luxury consumption of phosphorus and ultimately an increase in the population density of a few pollution tolerant forms and a reduction or elimination of pollution-sensitive species. This usually results in an overall increase in algal standing crop (or biomass) and a corresponding decrease in species diversity or species richness (Patrick, 1949, 1973, 1977; Cairns *et al.*, 1972; Cairns and Dickson, 1971). As a result of their sensitivity to chemicals added to their environment, periphyton are widely used as water quality indicators throughout the U.S. and Canada (Patrick and Reimer, 1966, 1973; Wetzel, 1979;).

Periphyton communities in the WCAs were studied by Swift (1981) and Swift and Nicholas, 1987) along a transect that traversed a gradient of increasing phosphorus concentrations in WCA-2A. Results of these studies showed that increased phosphorus concentrations in marsh waters were associated with (1) major changes in periphyton species composition, (2) reduced algal species diversity, increases in algal growth rates, and (3) increases in the phosphorus content of the periphyton community. Swift's work can be roughly divided into two segments. The first concerns a study conducted between February 1978 and August, 1979 at approximately two dozen stations within WCAs 1, 2A and 3A.

The 1978-1979 periphyton and nutrient water quality study demonstrated that; elevated phosphorus levels in the marsh south of the S-10 structures dramatically increased periphyton biomass production and fostered the development of a "specialized" algal community comprised of *Microcoleus lyngbyaceus* and a number of pollution tolerant diatom species" such as *Gomphonema parvulum, Nitzschia confervaceae, Nitzschia amphibia* and *Nitzschia palea* (Swift, 1981). Diversity was low while the algal standing crop increased at the nutrient-enriched sites. In contrast, interior marsh sites were dominated by species that were indicators of natural background water quality conditions such as the blue-greens *Schizothrix calcicola* and *Scytonema hoffmanni* as well as the diatom, *Mastogloia smithii*. The location of these findings is a set of seven sampling stations arranged in a straight line in WCA-2A in southerly direction from a point midway along L-39 between the S-10A and S-10C structures and numbered (from north to south) B-1 through B-7. This line of stations was referred to as "Transect B". These stations showed a definite linear progression of average total dissolved phosphorus concentrations between February 1978 and August 1979 from 0.09 mg/l at site B-1 to 0.045 mg/l at B-3, 0.022 mg/l at B-4 and 0.004 mg/l at sites B-6 and B-7. Indicator species of eutrophic water conditions characterized sites B-1, B-2 and B-3 but were absent from sites B-5, B-6 and B-7.

A follow up study conducted in 1980-1982 yielded dramatic results along Transect B in WCA-2A, with significant increases in total dissolved phosphorus concentrations at site B-5 located 3.7 km (2.3 miles) south of S-10C (Swift and Nicholas, 1987). Between 1978 and 1980, total dissolved phosphorus levels had ranged from below detection limits ($\leq$0.004 mg/l) to about 0.015mg/l. However, measurements as high as 0.075 and 0.12 mg/l were recorded in the fall of 1981 and ranged between 0.03 and 0.45 mg/l in the summer and fall of 1982 (Swift and Nicholas, 1987). Apparently as a result of the change in phosphorus levels, the periphyton community at Site B-5 now resembled those found at the high phosphorus sites, whereas in 1978 - 1979 and 1980, the periphyton species at Site B-5 were typical of sites where nutrient concentrations were much lower. When revisited in 1981 and 1982, Site B-5 "was dominated by heavy growths of ... *Microcoleus lyngbyaceus* ... and the pollution indicator diatom *Navicula disputans....*" both of which peaked in population when total dissolved phosphorus measurements were highest ("Swift and Nicholas, 1987").

Thus, the later data not only confirms the association between elevated phosphorus levels and pollution-tolerant species, but also seemed to demonstrate that increased surface water phosphorus levels in WCA-2A resulted in radical changes in species composition: "Results of this study indicate that increases in marsh water N and P supplies ... promote major change in periphyton species composition ..." (Swift and Nicholas, 1987)." Increased phosphorus concentrations in marsh waters were also associated with reduced algal species diversity, increased growth rates of pollution tolerant algae, and increases in the phosphorus content of the periphyton community (Swift and Nicholas, 1987).

In addition, a nutrient dosing study (Flora *et al.,* 1987) was performed within ENP. According to the authors, marshes were subjected to nutrient concentration doses (including H_3PO_4) at levels significantly higher than presently exist in water entering the park (Flora *et al.,* 1987). At such increased levels, the authors report loss of the native periphyton mat as a result of phosphorus enrichment, significant shifts in periphyton, and macrophyte species composition and alteration of the diel dissolved oxygen regime.

Impacts on Everglades Microbiology. Increased nutrient loading appears to affect microbial populations (bacteria and fungi) that are responsible for the decomposition of leaf litter within marsh. Reeder and Davis, 1983 reported that anaerobic conditions (lack of oxygen) and reduced numbers of facultative decomposer microbes prevailed within the marsh leaf litter at nutrient-enriched sites located downstream from WCA-2A water management structures. They hypothesize that as nutrients are introduced into the marsh, leaf litter decomposition by aerobic and facultative microorganisms shift to obligate anaerobes. Bacteria and fungi suspended within the water column were also found at higher densities at sites with elevated concentrations of nutrients as compared to sites with lower nutrient concentrations (Reeder and Davis, 1983). Colony-forming bacteria were found to be an order of magnitude higher at the nutrient-enriched sites, although this difference was not statistically different (Reeder and Davis, 1983). This change in microflora was associated with prolonged, low or anoxic (zero dissolved oxygen) conditions present within nutrient-enriched areas of the marsh. As with Swift and Nicholas (1987), contemporaneous water quality sampling at the sites provided the basis for a correlation between observed phenomena and known phosphorus levels. Mean total phosphorus levels at the sites closest to L-39 ranged from 0.144 to 0.324 mg/l, while mean total phosphorus at the third site was 0.008 mg/l. Dissolved oxygen levels (D.O.) showed corresponding variations with mean levels between 0.2 and 0.5 mg/l for sites close to L-39 and 1.7 to 2.1 mg/l at the site located four miles to the south (Redder and Davis, 1983). Coupled with D.O. readings showing anaerobic conditions associated with high phosphorus levels, the authors concluded that anaerobic bacteria became dominant at the phosphorus enriched sites, although this phenomena was not tested (Reeder and Davis, 1983).

Some of Reeder and Davis' findings were confirmed by Belanger and Platko (1986). Three sites were selected in WCA-2A and D.O. levels were measured at each site during a six-month period. One site labeled "nutrient-enriched" was located near S-10C while the other two, labeled "sawgrass" and "pristine slough" were located near the 217 gage which is roughly in the center of WCA-2A. Mean diurnal D.O. values ranged from 0.1 to 2.2 mg/l at the enriched site (with all but one value being less than 1.0 mg/l) and between 2.1 and 5.4 mg/l at the pristine interior marsh sites. However, these results are not associated with contemporaneous water quality measurements.

Impacts on Everglades Macrovegetation. The response of Everglades macrovegetation to phosphorus enrichment appear to be somewhat similar to the effects recorded at the microbiological level. High concentrations of nitrogen and phosphorus allow pollution-tolerant species (cattails) to out-compete native Everglades flora (Davis, 1991).

Earlier studies concluded that the nutrient requirements of Everglades sawgrass communities were low compared to other species indicating that Everglades marshes had limited potential for nutrient-uptake (Volk *et al.*, 1975; Steward and Ornes, 1975b). Sawgrass is considered to be a species that is an indicator of low-nutrient conditions and is only competitive in nutrient-limited, fire-climax habitats typical of the interior Everglades marsh (Toth, 1988; Davis, 1991).

Studies conducted within WCA-2A show that cattails out-compete sawgrass in their ability to uptake nutrients and increase plant production during years of high nutrient input (Toth, 1988; Davis, 1991). Cattails are considered a high-nutrient status species that is opportunistic and is highly competitive, relative to sawgrass, in nutrient-enriched situations (Toth, 1988; Davis, 1991).

Marsh Nutrient Uptake Capacity. Based on cattail retention resulting from growth, death and two years of decomposition (Davis, 1991) a preliminary estimate of the vegetation uptake capacity for nutrient-enriched areas of WCA-2A was 1.67 grams of phosphorus per square meter per year ($g/m^2/yr$) This study indicated that both sawgrass and cattail communities deposited phosphorus and nitrogen in the detritus as the result of leaf growth, death, and two years of decomposition. Annual phosphorus uptake by growing cattails was ten times that of sawgrass. However, dying cattails lose proportionally larger amounts of phosphorus as compared to sawgrass. The amount of phosphorus remaining in standing dead leaves is comparable for both species. Rates of phosphorus storage in leaf detritus represent 89 percent of the total retention by sawgrass and 86 percent of the total retention by cattail when root and rhizome storage is added (Toth, 1987 and 1988). Sawgrass and cattail stands accumulated detritus after two years of decomposition, contributed to the accretion of organic sediment, and deposited nutrients within these sediments (Davis, 1991).

Nutrient deposition estimates for non-enriched sites in the Everglades are approximately equivalent to accretion estimates for other oligotrophic peatlands and backwater marshes (Davis, 1991). Davis (1991) calculated mean retention rates of 0.18 $g/m^2/yr$ phosphorus and 7.5 $g/m^2/yr$ nitrogen by leaf detritus at the Everglades background site. These values are comparable to calculated values of <0.1-0.2 $g/m^2/yr$ phosphorus retention and 0.1 - 4.7 $g/m^2/yr$ nitrogen retention through peat accretion in northern oligotrophic wetlands (Nichols, 1983). Nutrient retention estimates at the Everglades background site are also similar to measurements of 0.5 $g/m^2/yr$ phosphorus and 9.0 $g/m^2/yr$ nitrogen retention in accreting sediments in a Louisiana backwater marsh (Hatton *et al.*, 1982), although Louisiana sediments contained both mineral and organic matter. As a result of the spread of nutrients across the northern portion of WCA-2A, the background site is currently (1990) considered to be located within the nutrient transition zone (Davis,1991).

Accumulation of Phosphorus in Litter. Litter breakdown has been reported to be largely complete after two years in some wetlands (Chamie, 1976; Day, 1982). Nutrient release from detrital material slowed before two years of decomposition was completed in the Everglades, as evidenced by little change in litter nutrient content during the last 6 to 12 months of the two-year decomposition period. Subsequent oxidation and mineralization of detritus may have been impeded by continuous flooding and the presence of reducing (anoxic) conditions in the detrital layer (Reeder and Davis, 1983). The observed reduction of nutrient release rates in Everglades detritus that occurred after less than two years of decomposition may explain the similarity of nutrient retention estimates at the background site to nutrient sequestration estimates in other non-enriched wetlands. Perhaps rates of long-term nutrient sequestration in accreting organic sediment in the Everglades sawgrass community are comparable in oligotrophic peatlands under natural low nutrient conditions. Similar litter half-lives in the Everglades and in a Michigan peatland (Kadlec, 1989) support this interpretation.

Phosphorus Retention due to Leaf Production after 2 years of Decomposition. In areas where surface water nutrient concentrations were higher in the Everglades, nutrient retention rates in two-year old leaf detritus were higher, up to a finite capacity (Davis, 1991). Rates of 1.1-1.4 $g/m^2/yr$ phosphorus and 17-18 $g/m^2/yr$ nitrogen retention by sawgrass and cattail may represent upper limits of nutrient retention resulting from leaf production and two years decomposition (decaying) in nutrient-enriched Everglades habitat; these rates were equaled or exceeded downstream along the surface water nutrient gradient (Davis, 1991).

Comparison with Results of Other Researchers. Increased rates of nutrient retention might also be expected based on comparison with other studies. The finding of higher rates of detrital nutrient retention at enriched Everglades sites, in combination with the decline in surface water phosphorus and nitrogen concentrations downstream along the nutrient gradient below inflow structures, agree with the conclusion of Kadlec (1989) that the litter zone in a Michigan peatland receiving secondary effluent retained a large fraction of the nutrients added over a 10-year period.

Greater detrital nutrient retention at enriched Everglades sites also agrees with the review of Richardson and Nichols (1985) of loading-retention relationships in northern wetlands receiving wastewater, where phosphorus removal increased up to 7 $g/m^2/yr$ as loading increased (**Table 35**). But a corresponding decrease in

Table 35. Effects of Loading Rate on Nutrient Uptake Capacity of Wetland Plant Communities.

Reference	Loading Rate g P/m2/yr	Uptake Rate g P/m2/yr
Boyt *et al* (1977)	0.9	0.78
Davis (1990) *(assuming 6000 Acres of Cattail-Impacted wetlands)*	2.22	1.67
Yonika and Lowry (1979)	7.1	3.34
Spangler *et al* (1977)	15.2	4.86
Ewel and Odum (1979)	17.2	7.00

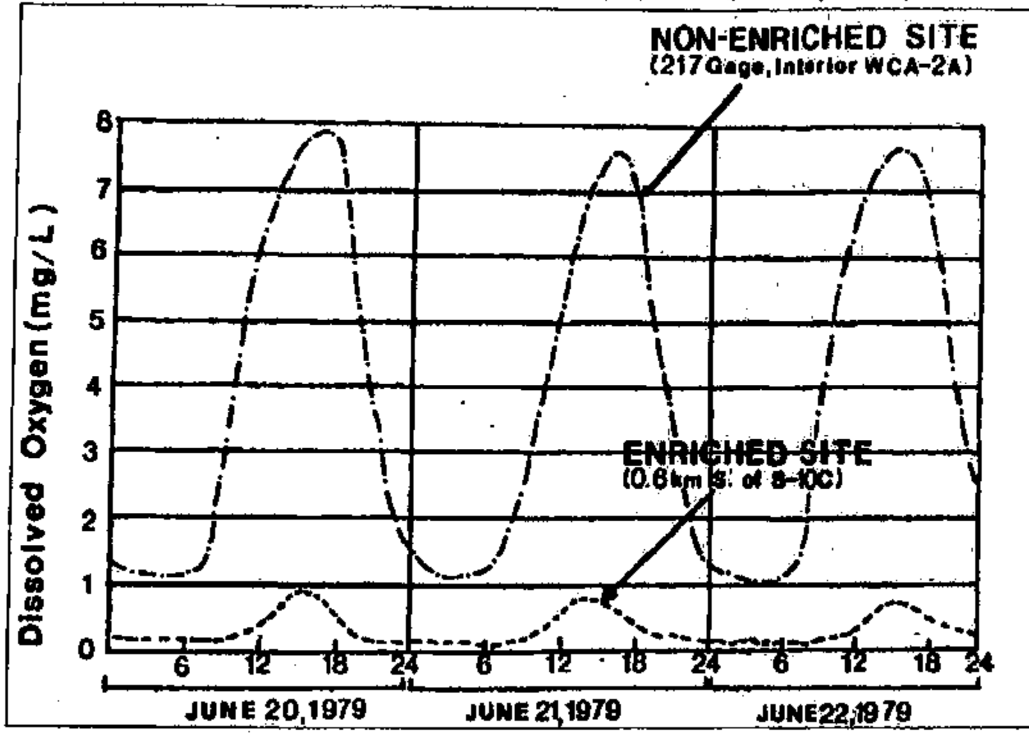
Source:Staff presentation to SFWMD Governing Board,December 1989

nutrient uptake efficiency (% of inputs) as loading increased (Richardson and Nichols, 1985) also suggests that wetland nutrient retention capacity may be limited, as appears to be the case for Everglades macrophytes stands.

Impacts on Marsh Community Metabolism. The community metabolism and dissolved oxygen regime of a freshwater ecosystem is often used as a measure of its environmental quality since both aquatic animal and plant life are dependent upon aerobic metabolism (Odum, 1971). During 1985-1986 the SFWMD funded an investigation of the dissolved oxygen content and 24-hour community metabolism characteristics of WCA-2A surface waters (Belanger and Platko, 1986). This study attempted to identify the various sources and sinks responsible for oxygen production and uptake within three contrasting marsh vegetation community types including (a) a nutrient enriched site dominated by cattail vegetation, (b) an interior (non-enriched) sawgrass site, and (c) an interior (non-enriched) aquatic slough site. Samples were collected at each site on a diurnal basis on six different dates, with the exception that the slough site was sampled on only five different dates.

Results of Belanger and Platko's work compare well with previous dissolved oxygen monitoring data collected by SFWMD staff in 1979 (**Figure 39**). Both sets of data show that dissolved oxygen levels in Everglades sawgrass stands and aquatic sloughs unaffected by high nutrient inputs fluctuate widely on a daily basis (**Figure 39**). Belanger and Platko (1986) indicated that daytime maximum concentrations

Figure 39. Diurnal Dissolved Oxygen Curves at Nutrient Enriched and Non-Enriched (Background) Marsh Sites in WCA-2A, June,1979.



Source:SFWMD Unpublished Data

frequently exceed saturation levels, while minimum values regularly fall below 2.0 mg/l. In comparison with the non-enriched interior marsh sites, the nutrient enriched site (site B-2) experienced significantly lower dissolved oxygen maximums, lower daily minimums, lower percent saturation levels, and frequent prolonged anaerobic conditions during warm weather. On the dates sampled in 1985, mean dissolved oxygen levels at the nutrient enriched site, ranged from less than 0.1 to 2.2 mg/l (**Table 36**). Dissolved oxygen concentrations at the sawgrass site ranged from 1.4 to 4.9 mg/l. Highest concentrations were observed at the aquatic slough site with mean values varying between 2.1 and 5.4 mg/l as shown in (Belanger and Platko, 1986). Sediment oxygen demand represented the major oxygen sink at each marsh site, while atmospheric diffusion represented the primary oxygen source at the nutrient-enriched and pristine sawgrass sites. Higher oxygen levels observed at the aquatic slough site were assumed to be the combined result of atmospheric diffusion and periphyton photosynthesis, while oxygen uptake was a result of sediment uptake and nighttime respiration by the periphyton mat. Oxygen production by plankton and oxygen consumption by bacteria or chemical components was minimal (Belanger and Platko, 1986).

Community metabolism, a measurement of dissolved oxygen production and consumption, was estimated at each site. Community metabolism at the nutrient enriched site and within the sawgrass stand exhibited an oxygen deficit, indicating the demand for oxygen exceeded daytime oxygen production by aquatic vegetation. Although both sites exhibited depressed oxygen levels, only the nutrient enriched site displayed prolonged periods of anoxia (Belanger and Platko, 1986). The slough habitat in some instances, experienced a positive oxygen balance indicating that more oxygen was produced than consumed. This increase was credited to the presence of a submerged periphyton algal mat, which was absent at the other

Table 36. Comparisons of mean 24-hour Dissolved Oxygen Concentrations and Percent Saturation Values at a Nutrient-Enriched marsh site versus two "Pristine" Non-enriched marsh sites located in WCA-2A (From: Belanger and Platko, 1986).

Site Description	7/17/85	8/9/85	9/5/85	9/25/85	11/13/85	12/17/85
Nutrient-Enriched site (site B-2)	0.4* (5%)	0.1 (1%)	0.1 (1%)	0.5 (6%)	0.8 (9%)	2.2 (24%)
Pristine Sawgrass site (near 217 gage)	3.5 (43%)	1.4 (19%)	3.1 (39%)	2.7 (35%)	3.4 (40.%)	4.9 (50%)
Pristine Aquatic Slough site (near 217 gage)	4.5 (56%)	2.1 (28%)	3.5 (43%)	nd	3.4 (40.%)	5.4 (54%)

* = number without parentheses represents mean dissolved O_2 concentration (mg/L), number in parentheses represents calculated percent saturation level based on D.O. and temperature data, nd = no data.

stations. The results of Belanger and Platko (1986) compare well with the results of other water quality/biological studies conducted within the northern portion of WCA-2A where continuously low dissolved oxygen levels and occasional periods of anoxia prevail within nutrient-enriched portions of the marsh (Reeder and Davis, 1983; Swift and Nicholas, 1987).

Additional marsh community metabolism data was collected by SFWMD biologists from 1981-1983. Dissolved oxygen concentrations were monitored at three interior WCA marsh sites unaffected by nutrient inflows (site A-3, WCA-1; the 3-4 gage, WCA-3A; the 217 gage, WCA-2A) and one nutrient-enriched site (Site B-2, WCA-2A) located within cattail vegetation in the north end of WCA-2A (Swift, unpublished data). All sites monitored were open water sloughs. Diurnal temperature and dissolved oxygen data were monitored every half hour using electronic dissolved oxygen meters (YSI model 56) calibrated in the field by Winkler titrations. The free-water diel oxygen method described by Odum and Hoskin (1958) converted to a USGS computer program (Stephens and Jennings, 1976) was used to determine the community metabolism characteristics of each site using the collected diurnal data.

Table 37 provides a summary of means, standard deviations, ranges and percent saturation for all data collected from the four sites from 1981-1983. Low

Table 37. Mean, Standard Deviation Dissolved Oxygen Concentrations and Percent Saturation Data from Four Selected WCA sites, 1981-1983.

Station	Mean D.O. Concentration (Standard Deviation)*	Range, Min-Max * Concentration	Range, Min-Max % Saturation	Percent of observations below 5.0 mg/l standard
P-Enriched site B-2 (WCA-2A)	0.86 (0.80)	0.0 -3.6	0-48%	100%
217 gage (WCA-2A	4.6 (3.23)	0.2- 13.5	0 -146%	60.2
A-3 (WCA-1)	4.11 (2.45)	0 -13.2	0 -139%	64.8
3-4 gage (WCA-3A)	5.91 (2.16)	0.9- 11.4	9.8- 138%	33.0

* = mg/l as Dissolved Oxygen; SFWMD, Unpublished data

dissolved oxygen (D.O.) levels were consistently observed from the nutrient-enriched (B-2) site with an average concentration of 0.9 mg/l over the study period. Dissolved oxygen concentrations at site B-2 never reached higher than 3.6 mg/l for the entire study period and did not meet the state water quality criteria of f 5.0 mg/l for Class III waters (**Table 37**). In contrast, non-enriched, background sites showed wide diurnal variations in D.O. content with daily values ranging from zero to 13.5 mg/l (0-146 percent saturation). Average D.O. levels for the 3 control sites ranged from 4.1 -5.9 mg/l (**Table 37**). These variations, to a large extent, are probably the result of biological activity (plant photosynthesis and respiration) associated with the abundant periphyton-*Utricularia* spp. (bladder wart) mat present at the interior marsh sites (Hunt, 1961; Wilson, 1974). The absence of the periphyton (*Utricularia* spp.) mat is thought to be responsible for the consistently low D.O. values recorded at the B-2 site as cited by Belanger and Platko, 1986). Supersaturated conditions (concentrations exceeding 100 percent saturation) in late afternoon and low early morning D.O. concentrations (<2.5 mg/l) appear to be the commonplace in the Everglades marsh.

Table 38 provides a summary of averaged community metabolism data collected from the four sites. These data include net daytime O_2 production (grams O_2 /m^2 produced during daylight hours), night respiration (grams O_2 /m^2 consumed during the night), 24 hour net community metabolism (grams O_2 /m^2 produced per day minus grams O_2 /m^2 consumed per day) and calculation of a production/respiration ratio (P/R ratio)as shown in **Table 38.**

Table 38. Average Community Metabolism Data for Selected WCA Marsh Sites, 1981-1983.

	Net Daytime Production	Night Respiration	24 Hour Net Community Metabolism	P/R-Ratio
Interior Marsh Sites				
A-3 (WCA-1)	1.09*	-1.11	-0.01	0.99
217 (WCA-2A)	1.05	-1.12	-0.05	0.95
3-4 (WCA-3A)	0.95	-0.92	-0.008	1.09
Nutrient Enriched Site				
B-2 (WCA-2A)	-0.006	-0.22	-.22	-0.01

SFWMD, Unpublished data *Units = grams O_2/M^2 day-1 uncorrected for diffusion

Results showed that on the average, interior marsh sites unaffected by nutrient-enrichment produced and consumed approximately 1.0 gram of O_2 /m^2 /day. P/R ratios at these background sites ranged between 0.95 and 1.09 generally averaging near 1.0. Aquatic communities which produce P/R ratios near 1.0 generally represent stable, balanced ecosystems that have developed over long periods of time (Odum, 1971). Such balanced ecosystems include coral reefs, mature tropical rain forests and oceanic plankton communities. Pomeroy (1970) considers P/R ratios near 1.0 to be characteristic of systems where nutrients available for production are largely determined by recycling mechanisms.

In contrast, the community metabolism characteristics of the nutrient-enriched (B-2) site was dominated by respiration (O_2 consumption) with little or no oxygen produced on a daily basis. P/R ratios at this site average -0.01 grams O_2/m^2/day (**Table 38**) indicating that oxygen-consuming processes dominate nutrient enriched areas of the WCA marsh.

Summary of Water Quality Impacts. These studies provide evidence that Everglades marshes are sensitive to increased nutrient concentrations which are in fact being discharged into those marshes. Swift and Nicholas (1987) showed that dramatic impacts on periphyton species composition develop relatively quickly when nutrient concentrations increase. Dissolved oxygen levels also plummet and the aerobic/facultative bacterial community shifted to one dominated by anaerobic species in response to similar water quality stress. Moreover, cattail out-competes the presently dominant sawgrass in conditions of elevated nutrient concentrations. However, even cattail uptake seems to have a retention capacity which suggests that when that limit is reached, water-borne nutrients will continue to pass downstream to create new impacts (Davis, 1991).

All of these studies and data must be assessed in the context of a marsh system which is oligotrophic. This essentially means that Everglades marshes were historically characterized by relatively low levels of nutrients and the mix of floral and faunal species includes or is dependent upon species which evolved in or are adapted to low-nutrient conditions. Therefore, the impacts of additional discharges of elevated surface water nutrient concentrations will continue to multiply beyond those summarized above which are already occurring.

Circumstantial evidence that the Everglades was historically an oligotrophic system comes from a number of sources. For example, historical surface water quality measurements from marsh sites far in the interior of the WCAs and adjacent to ENP in the east Everglades yielded nutrient concentrations well below the limits correlated with the phenomena observed by Swift and Nicholas (1987) and Reeder and Davis (1983). The United States Geological Survey conducted a two-year program of monthly surface water sampling at 25 stations in C&SF Project canals, the WCAs and in Taylor Slough adjacent to the Park from 1972 through 1974 (Waller and Earle, 1975). Three of the sampling points were located in the interiors of WCA-1, WCA-2A and WCA-3A, far removed from District structures or canals. One was located in a canal in Taylor Slough, adjacent to the Park. Average nonflow weighted total phosphorus concentrations readings at these sites ranged from 0.012 to 0.023 mg/l for the two-year period (Waller and Earle, 1975; Basic Data B).

An additional source of information is the likelihood that rainfall constituted the primary source of nutrients to the Everglades prior to human settlement of the region when most of the plant and animal species became established. The same U.S.G.S. study measured nutrients in rainfall at two sites on the edge of WCA-3A. Over the same 1972-1974 period, the nonvolume-weighted average total phosphorus measurements were 0.032 and 0.035 mg/l at these stations, excluding contaminated samples (Waller and Earle, 1975).

Also, studies of sawgrass portray a species highly adapted for life in a fire climax oligotrophic ecosystem. Steward and Ornes (1975a) estimated that sawgrass has an apparently low nutrient requirement and that phosphorus is on a tight cycle in the Everglades. Sawgrass appears to be well adapted to make the most of relatively scarce supplies of nutrients in the environment. The fact that sawgrass dominates vast portions of the Everglades, both today and historically, provides further circumstantial evidence that the system has been historically oligotrophic.

The ramifications of discharging water with elevated nutrient concentrations into a highly interrelated, complex biological system adapted to low nutrient conditions are significant. For example, rapid, dramatic shifts in periphyton species composition as described by Swift and Nicholas (1987) as correlated to nutrient concentrations around 0.05 mg/l or higher could threaten the Everglades food web. Controlled feeding experiments with native Everglades tadpoles and common South Florida periphyton species showed a significant relationship between the species composition of the periphyton food source and weight gain in tadpoles feeding on periphyton (Browder, 1981). Although there is much to be learned about the role of periphyton in the Everglades food web, a substantial body of research in Everglades habitats demonstrates that these algal species form the base of an interlocking system of food chains with predators at the top (Hunt, 1961; Ogden *et al.*, 1978; Kolipinski and Higer, 1969; Loftus *et al.*, in press). Complex food webs may have modest beginnings as demonstrated by the role of mangrove leaf litter in detritus-based food webs (Odum *et al.*, 1982; Odum, 1970, 1971; Heald *et al.*, 1974). Wading bird populations in the Everglades are believed to be delicately balanced with fish species that in turn may depend on aquatic microorganisms (Ogden, 1978).

Periphyton also probably play important roles in controlling surface water dissolved oxygen concentrations (Hunt, 1961; Wilson, 1974; Belanger and Platko, 1986) and formation of marl soils (Gleason, 1972; Gleason and Spackman, 1974).

Therefore, there is valid reason for concern that the documented shifts in periphyton species associated with elevated nutrient conditions following drought conditions could signal long-term, adverse changes in the ecosystem with widespread ramifications to Everglades vegetation, fish and wildlife. Evidence that elevated nutrient concentrations are associated with changes in dissolved oxygen cycles and a shift to anaerobic conditions in a system that appears to be adapted to low nutrient concentrations also creates grounds for concern.

Finally, changes at higher nutrient levels among macrophytic vegetation should also be expected. Davis (1991) showed that although sawgrass and cattail are both adapted to flourish in low-nutrient systems, cattail takes advantage of high-nutrient conditions while sawgrass does not. Moreover, field observations over a ten-year period have indicated a gradual increase in cattail abundance in sawgrass marshes in WCA-2A where cattail was previously rare or absent. Elevated nutrient concentrations have been measured in these same areas during this same period. In fact, a band of vegetation characterized predominately by cattail has existed for years parallel to and south of L-39 in WCA-2A east of S-10D, in an area characterized by elevated nutrient concentrations according to long-term water quality data. Although small stands of cattail-dominated areas exist throughout the WCAs, this band, possibly encompassing thousands of acres, is not.

These phenomena all provide evidence that elevated nutrient concentrations in waters discharged to the WCAs are causing shifts in floral populations to favor those species that are tolerant of, or that thrive in, such conditions as opposed to species adapted to historic oligotrophic conditions in Everglades marshes (see also discussion of "Water Quality Impacts on Everglades Habitat", Planning Document).

7. Recreational Uses.

Outdoor recreational development within the WCAs has generally followed the recommendations set forth in two published plans - Recreation Plan, the Area South of Lake Okeechobee, prepared in 1960 for the District by the Florida Development Commission and Recreational Development of the Florida Everglades Water Conservation Areas: Five-Year Plan 1973-1978 prepared in 1974 by the Everglades Recreational Planning Board. Over the years, numerous access sites and several full scale concession operations have been developed by federal, state and local agencies to facilitate use and enjoyment of these areas by the general public.

WCA-1. Recreational activities in WCA-1 are regulated by the U.S. Fish & Wildlife Service (USFWS) which manages this area as the Arthur R. Marshall Loxahatchee National Wildlife Refuge under a Cooperative and License Agreement with the District. Fishing, boating, nature observation, and commercial airboat rides are among the more popular activities pursued by refuge visitors. Waterfowl hunting is permitted during the hunting season although refuge personnel report that interest in this activity appears to be waning along with a decline in waterfowl populations on the refuge. Major attractions include the Hillsboro Concession Facility (Loxahatchee Recreation Area), a full-service concession facility at the south end of the refuge, and the Headquarters Complex which includes an interpretive center, nature boardwalk, and wildlife observation areas and a seven-mile canoe trail. Visitors must pay a daily entrance fee and possess valid state hunting and fishing licenses when engaged in those activities. Airboat use is by permit only and restricted to certain designated areas of the refuge. Nighttime use is prohibited. In 1986, 50,000 persons toured the wildlife center. An estimated 300,000 persons use the Hillsboro entrance to the refuge taxing the carrying capacity of the current facility (LOTAC-II, 1988). In all, nearly 500,000 people visit the refuge each year.

WCA-2. Management of the fish and wildlife resources and recreational use within WCA-2 and WCA-3 is handled by the FGFWFC under a Cooperative and License Agreement with the District. The FGFWFC operates these areas as the Everglades Wildlife Management Area (WCA 3-B is a subunit designated as the Francis Taylor Wildlife Management Area). Fishing, airboating, hunting, and frogging are the primary activities. WCA-2 is served by two full service concession operations - the Hillsboro Concession Facility (Loxahatchee Recreation Area) located at the northeast corner of the area and Sawgrass Recreation Area off U.S. 27. Airboat tours have proven to be a popular tourist offering at most of these businesses. Visitors must possess a valid hunting or fishing licenses as well as a valid wildlife management area stamp when engaged in those activities. Airboats, tracked vehicles, are typical of the specialized ORVs that are commonly used to access the interior reaches of WCA-2 and WCA-3. Nighttime use is permitted; however, all or a portion of the areas may be closed by the GFC during emergency conditions (such as fire or high water) and use of tracked vehicles is limited to certain periods of the hunting season in WCA-3.

The many miles of canals within the three WCAs offer excellent fishing and boating opportunities. In WCA-2A the borrow canals for L-38E, L-38 and L-35B offer approximately 21 miles of unrestricted boating. As a general rule navigation is unobstructed in these canals except on those occasions when sections become infested with floating aquatic weeds (water hyacinth or water lettuce) or during extreme low water periods when rocks are often exposed or near the surface along the edges.

<u>Estimated Fishing Use</u>. The FGFWFC 1986-1987 annual report for the Everglades area (including the WCA-3 portion) estimates that 128,430 man-hours were expended by fishermen over the six-month (December through May) season. Converting this statistic to a seven-month (December through June) peak fishing season, and using a rate of six man-hours per recreation day (FGFWFC, 1987), with an assumed peak season use to annual use ratio of 55 percent, the recorded 21,405 days of visitor use for the surveyed six month period can be translated into 38,900 recreation (visitor) days of fishing use. Unlike airboating and frogging, fishing use is considered to not overlap with other recreational activities on a per person basis at this resource. FGFWFC 1987-1988 data for WCA-2 indicate that 21.1 percent of fishing in this area is bank fishing (panfish, catfish) and 78.9 percent is boat fishing. WCA-2A bankfishing harvests exceeded that found in other areas. WCA-2B is preferred by largemouth bass anglers. In general, sport fishing productivity has increased along the marsh rim canal in recent years. FGFWFC's 1987-1988 surveys indicate that non-residents constituted 12.9 percent of fishermen surveyed, up from 5.5 percent in 1985-1986.

Impacts of management practices on recreational resources and use. The water levels within the WCAs impact recreation and public access both directly and indirectly. The mode of transportation needed to travel in the interior portions is directly affected by water levels. If there is sufficient water within the marsh, travel by airboat is possible. If not, tracked vehicles or specially designed ORVs that do not sink into the soft organic peat soil are required.

The WCAs produce both a marsh and canal fishery. During high water periods the fish tend to move out of the canals into the adjacent marshes to spawn and forage. The fish are scattered; however, knowledgeable fishermen who understand how fish become concentrated into deep water areas of the marsh often record some spectacular catches. Fishing in the canals is generally slower during these periods; but, as water levels recede, the fish move back into the canals, and fishing improves dramatically. As a rule, high water conditions extending over two years or more produce larger fish. These conditions have occurred on several occasions over the past thirty years, and each was followed by a phenomenal period of fishing. Extremely low water conditions can also result in spectacular periods of fishing as the fish become more concentrated in the canals. Unfortunately, if water levels recede too far, the result is often a fish kill.

Extended periods of subnormal rainfall result in dry conditions favorable for the expansion of the deer herd and increased quotas for hunters. While deer numbers increase, the long-term affect on the quality of hunting does not. Competition for available forage increases, and in past high water periods the animals become more susceptible to die off from disease and malnutrition. High numbers also may result in a reduction in the average size of the animals and smaller antlers. The FGFWFC's prevailing management practices are designed to maintain a smaller herd, well within the carrying capacity of the areas during high water conditions. Proper water level conditions during the annual waterfowl season are also necessary to attract waterfowl to the WCAs . Good quality hunting depends on an adequate supply of the birds, but water levels are not the only factors affecting waterfowl use of the areas.

Management practices can and do influence the amount and timing of water deliveries to and from these areas, but water conditions are often more dependent on general rainfall patterns. Water conditions that are optimum for one species or activity are not necessarily the same for another, and there is a growing acceptance of the idea that the most appropriate water regimen for the WCAs is that which is necessary to restore and maintain some semblance of the habitat patterns in existence prior to construction of the retaining levees.

WCA-3. WCA-3 is served by Everglades Holiday Park, a full service concession located near Pump Station S-9, two private fish camps on the Miami Canal, and several business operated by Miccosukee Indians along the Tamiami Trail. Airboat tours have proven to be a popular tourist offering at most of these businesses. Visitors must possess valid hunting or fishing licenses as well as a water management area stamp when engaged in those activities. Airboats, tracked vehicles, and an assortment of specialized ORVs and ATCs are commonly used to access the interior reaches of WCAs 2 and 3. Nighttime use is permitted; however, all or a portion of the areas may be closed by the GFC during emergency conditions.

The many miles of canals within the three WCAs offer excellent fishing and boating opportunities. The largest network of canals is contained in WCA 3A where it is possible to go by boat from the northeast corner of the area at the intersection of

L-5 and L-38W to the southwest corner along the Tamiami Trail - a distance of approximately 56 miles. As a general rule, navigation is unobstructed in these canals except on those occasions when sections become choked with aquatic weeds or during extreme low water periods when rocks are often exposed or near the surface along the edges. One major exception involves portions of the Miami Canal and the Alligator Alley Borrow Canal where access to the remainder of the canal system has been cut off by the installation of water control structures and earthen plugs designed to restore sheet flow from the north to the south sides of the highway.

Recreation Access and Management Issues. There are a number of current issues that impact public access to the WCAs. Among the more prominent are: (1) the conversion of Alligator Alley to I-75, (2) the maintenance of boat ramps and access areas, (3) vandalism of vehicles and equipment, (4) control of unauthorized overnight camping, and (5) the regulation of hunting camps. The Miccosukee Indian Tribe has use rights to WCA 3A south of Alligator Alley and, hence, impact the availability of public recreation hunting and fishing in this area.

The many bridge sites along Alligator Alley have been used informally by bank fishermen for many years, and sportsmen have enjoyed the use of the Miami Canal Rest Area and boat ramp at the eighth bridge (west from U.S. 27) for hunting and fishing access into the interior portions of WCA-3A. The conversion of the highway to a limited access interstate will result in a net loss of access because motorists will no longer be able to pull off the roadway and fish at the many bridge sites. A major access site is proposed for location at the Miami Canal; however, it is not clear whether the present degree of access will be maintained. Without the construction of additional sites, it appears likely that boating access to certain reaches of the highway borrow canal will be lost.

At present, some of the access sites to WCA-2 and WCA-3 are not maintained on a regular basis, and there is little agreement as to which agency is responsible. As a result, many sites remain in an unkempt and littered condition for extended periods of time. The FGFWFC has a program for the construction and repair of boat ramps; however, federal funds are involved, and they must have an easement or agreement covering the ramp location from the underlying owner. A prototype agreement is being reviewed by the District, and, if approved, it should expedite future ramp repair in these areas. Reports of fishermen and hunters returning to launching sites to find their vehicles and trailers stolen or vandalized appear to be on the increase. Other than increased law enforcement patrol, there appears to be little that can be done to remedy the problem since many of the sites are in remote locations.

Overnight camping along certain reaches of L-29 at the south end of WCA-3 has become a problem in recent years. Certain individuals - many winter visitors - have been residing in their RVs for extended periods of time at locations that are not developed and equipped for such use. Legitimate public health concerns and questions about the propriety of such use have been raised, and recently, the District took action to evict the squatters and post the locations to restrict overnight use. There appears to be a need to address this problem area wide.

The construction of permanent hunting camps in the interior of WCA- 2A and 3A has been a matter of controversy for many years. In the mid-1960s the District and the FGFWFC attempted to regulate the camps under a permit system. The effort was abandoned after an attorney general's opinion was received advising that the agencies could only regulate the camps if they owned the underlying land. To this day the camps remain unregulated; and there have been no attempts by local government to address the problem. Over the years some camps have been abandoned, some burned down, and new ones built. Current estimates place the number of camps in WCA-2 at 19 and in WCA-3 at 55. There are two primary concerns over the camps - one relating to the lack of adequate waste disposal facilities and the other concerning the occupancy of elevated sites needed for wildlife during periods of high water. There have also been allegations that some camps have played a role in drug trafficking and poaching. The Miccosukee Tribe derives a substantial income by charging annual permit fees for similar camps located on the Reservation.

C. BASINS EAST OF THE WATER CONSERVATION AREAS.

1. Basins Included.

Sections of the eight basins lying immediately east of and adjacent to the Water Conservation Areas are included in the Plan's study area for assessment of existing and potential Everglades impacts. These basins run the length of the WCAs' eastern levees, from State Road 80 in Palm Beach County to Tamiami Trail (U.S. 41) in Dade County.

The areas encompassed by this plan include the western sections of the C-51, C-11 and Hillsboro Canal basins, and parts of the C-14, C-13, North New River Canal, C-9 and C-4 basins. Additionally, an area west of State Road 7 between the C-51 and Hillsboro basins is included, because the largely undeveloped area contains extensive wetlands which were once part of the Everglades. Some of this land, such as the Strazzula tract in Palm Beach County, has already been purchased by the District under the Save Our Rivers program.

2. Basis for Inclusion.

Relation to the Historic Everglades. Much of the land lying between the Everglades levees and State Road 7 was once part of the Everglades. In some areas, large portions of these basins have been drained for development by the regional flood control system and by secondary drainage systems. In other areas, extensive wetlands remain, but generally are expected to come under increased pressure for development.

These basins generally are not natural tributaries of the WCAs. In addition, any areas that were tributary, have been isolated from the remaining Everglades system by the construction of the WCA perimeter levees. Several areas have become tributary to the WCAs with the construction of facilities to backpump water into the Everglades for flood control or water supply purposes. The remainder of the eastern basins have been proposed or studied at one time or another for either flood control or water supply backpumping plans. The eastern basins all receive water supply benefits from the WCAs, either directly from WCA water releases or indirectly when water from Lake Okeechobee passes through the WCAs and to the coast by way of the regional canal network.

Pressure for Development. Many areas of the eastern basins are now rapidly urbanizing. The western portions include extensive acreages of flood-prone, former swamp land which has been converted, or is undergoing conversion, to residential and commercial uses. Rapid growth has raised concerns about the level of flood protection that can be provided by regional and secondary systems, impacts on the WCAs from increased flood protection and water supply demands, and the possible wildlife impacts due to loss of natural habitats and urban development immediately adjacent to the Everglades.

Backpumping. Backpumping occurs at one major structure (S-9) in the C-11 basin and several smaller facilities, including the G-123 in the North New River Basin (which may also pull some excess waters from part of the C-13 basin). Both structures discharge into WCA-3A. Two non-District pumping operations also exist, including the Acme Improvement District's pump stations serving the Wellington area in Palm Beach County, and pumps owned and operated by the North Springs Improvement District, serving part of Coral Springs in the C-14 Basin of Broward

County. The Acme pumps discharge into WCA-1, while the North Springs pumps discharge into WCA-2A.

Other Issues. Other major issues surrounding the basins east of the WCAs eastern basins are primarily growth-related and include the following:

- Increased need for water supply and flood control facilities in areas adjacent to the WCAs. Of special concern is the need to implement effective water conservation measures in Dade, Broward and Palm Beach counties.
- Proposals for transportation facilities, including airports and highways, adjacent to and within the WCA system.
- Increased need for utilities service lines, including, but not limited to, power lines and telephonic transmission towers.
- Encroachment of urban development adjacent to the WCAs, where flood control and other urban services may cause seepage problems or other concerns for the WCAs.

The District is already addressing these and a variety of other water resource issues in the western sections of the southeast coastal counties and will incorporate the objectives and strategies of this plan into these ongoing growth-related planning efforts.

3. Land Use

Land use in the basins east of the WCAs is summarized in Table 39. The western C-51 and the Acme Drainage District are the primary basins in Central Palm Beach County. The western C-51 Basin contains 90,000 acres, of which the majority (47,000) acres is in urban land uses. This basin contains includes portions of

Table 39. Generalized 1987/1988 Land Use/Land Cover Types and Acreages by Watershed for the Eastern Basins of the Everglades SWIM Study Area.

Basin	Land Use Type							
	Agriculture, acres (% basin)	Urban, acres (% basin)	Rangeland, acres (% basin)	Forested, acres (% basin)	Wetlands, acres (% basin)	Water, acres (% basin)	Barren Land, acres (% basin)	Totals, acres (%)
Acme	4,104 (33.6)	5,408 (44.3)	1,147 (9.4)	790 (6.5)	643 (5.3)	73 (.6)	55 (.4)	12,220 (100.1)
W C-51	21,823 (24.3)	46,712 (52.1)	308 (.3)	6,827 (7.6)	12,185 (13.6)	1,682 (1.9)	172 (.2)	89,709 (100.0)
C-13W	87 (.7)	11,587 (88.2)	660 (5.0)	48 (.3)	217 (1.7)	544 (4.1)	--	13,143 (100.0)
C-11W	12,165 (23.1)	19,498 (37.1)	11,805 (22.4)	1,854 (3.5)	5,346 (10.2)	1,493 (2.8)	461 (.9)	52,613 (100.0)
Hillsboro Canal	21,090 (32.1)	31,794 (48.4)	881 (1.3)	6,047 (9.2)	2,826 (4.3)	1,773 (2.7)	1,212 (1.8)	65,623 (99.8)
C-14	823 (2.2)	32,189 (85.8)	365 (1.0)	1,815 (4.8)	449 (1.2)	1,508 (4.0)	372 (1.0)	37,520 (100.0)
North New River Canal	2,592 (10.1)	19,813 (77.6)	264 (1.0)	1,142 (4.5)	218 (1,474)	1,474 (5.8)	42 (.2)	25,545 (100.0)
C-9W	4,932 (16.8)	5,781 (19.7)	11,768 (40.1)	235 (.8)	4,586 (15.6)	1,093 (3.7)	958 (3.3)	29,353 (100.0)
C-4 "Area B"	12,579 (12.3)	30,725 (29.6)	4,769 (4.7)	1,799 (1.8)	43,873 (43.0)	4,855 (4.8)	3,527 (3.5)	102,127 (99.7)

the fast-growing communities of Loxahatchee Groves, Wellington and Royal Palm Beach. Approximately 21,000 acres (23%) of this basin consists of forests, wetlands and open water. The Acme Drainage District is located in the southwestern portion of the C-51 Basin, but discharges directly into the WCAs through a privately owned and operated pump station. This 12,000-acre subbasin is comprised primarily of urban (44%) and agricultural (34%) land uses. Agricultural uses include citrus, vegetables, cattle ranching, nurseries and small (5-10) acres family farms. Approximately 12% of the Acme basin includes forests, wetlands and open water.

In southern Palm Beach County and northern Broward County, the Hillsboro Basin has predominantly low density residential, some commercial land use, and a modest amount of agriculture.

In central Broward County, the C-14 and C-13 and C-11 Basins have mixed agricultural and urban land uses. The C-14 basin is highly urbanized, encompassing the city of Coral Springs and other Broward municipalities. The Sawgrass Expressway separates urban development from the WCAs, but is expected to spur more growth in remaining undeveloped areas in western section of this basin.

In southern Broward and Dade Counties, the C-9 and C-4 basins include some large tracts of undeveloped natural wetlands as well as mixed agricultural and urban land uses. Land use in the eastern portion of the C-4 Basin includes rock mining, open water rockpits, industrial, and low to medium density housing. The northern and western portions are mostly undeveloped wetlands.

4. County Summaries.

More than 3.5 million people live in the tri-county region of southeast Florida where rapid growth has brought urban development almost adjacent to the WCAs' eastern levees. A major toll road, the Sawgrass Expressway runs along the WCA-2 levee in north and central Broward County. Development of subdivisions and new communities such as Weston, Wellington and others is expected to continue in areas near the WCAs. Much of the land on which future development is expected to occur in all three counties is incorporated within the plan boundaries. Only parts of the previously identified basins are included in the Everglades SWIM study area in recognition of both direct and indirect impacts that growth in the western parts of the three counties could have on the WCAs.

While most of the counties' urban areas are not included within the study area, all three counties place major demands on the Everglades-Lake Okeechobee water supply system during times of drought and water shortages. Thus, several SWIM-related concerns are regional in nature, including some which apply to all three counties: the need for increased water conservation and investigation of water supply alternatives; protection and preservation of wetlands outside the WCAs for groundwater recharge and wildlife habitat; and the need to address impacts of stormwater discharge from existing and future development on water quality.

Palm Beach County. Palm Beach County has a 1988 estimated population of 830,000. Ten years from now, the population is projected to be 1.1 million, with the buildout estimate to be at 1.5 to 1.8 million. The West Palm Beach-Boca Raton Metropolitan Statistical Area (MSA) accounts for 80% of the County's current population. Limited groundwater supplies in northeast Palm Beach County require monitoring and protection to prevent or reduce saltwater intrusion, and to meet increasing demand. The cumulative affect of urban and agricultural runoff has generally caused degradation of water quality. Several basins in Palm Beach County have limited drainage and flood protection capabilities. In particular, the western C-51 and Hillsboro basins have existing flooding problems which are expected to get worse as development in the county continues.

Other issues in Palm Beach County which need to be addressed include water conservation efforts by local government, water supply interconnections with other utilities to ensure adequate water supply during drought or wellfield contamination, and stormwater discharge impacts on water quality and its effect on sensitive environmental areas and subsequent hydrologic connection to wellfields.

Broward County. Broward County has a current estimated population of 1.2 million. Population projections for the 2020 range from 1.7 to 2.3 million. Much of this growth is expected to occur in the southwestern portion of the county. The location of this growth will make drainage and flood control and the availability of potable groundwater supplies major concerns of the SFWMD. This is especially true in the western C-9 and C-11 basins, where a significant amount of the county's growth is expected to occur. Similar concerns exist in the Broward County portion of the western Hillsboro Basin, where discharges from new development in the 1970s and 1980s have greatly reduced the flood protection for the western basin.

Growth in Broward County is causing planned expansion of wellfields and additional groundwater withdrawals. These new withdrawals may have impacts on surface water hydrology. The conflicts between existing surface water uses and new groundwater uses is expected to increase. Some areas of Broward County are especially vulnerable to saltwater intrusion due to eastern locations of older municipal wellfields. The present strategy is to replace or supplement these older wellfields with new facilities located further west. A countywide water authority has been proposed but not implemented. In lieu of the countywide plan, the District is requiring the county and municipalities to examine other long-term water supply options including interconnections between utilities, wastewater reuse, and alternative supply sources.

Dade County. Dade County's 1988 population was estimated at 1.8 million. Projections for the year 2010 place Dade's expected population between 2.21 million and 2.5 million (Metro-Dade Comprehensive Plan, 1988). The state's most populous county is the District's largest water consumer. Metro-Dade has created a countywide water supply authority and generally relocated its wellfields to the western areas away from the threat of saltwater intrusion. However, increased demand has led to development of plans for additional wellfield capacity in the Northwest Wellfield, requiring additional water supply recharge from the Everglades. Also, future plans call for a new wellfield to be developed in the southwest part of the county in wetlands-dominated areas near the WCAs and the ENP.

Like Broward and Palm Beach counties, much of Dade's growth in the late 1990s and into the 2000s is expected to occur in fringe areas containing extensive wetlands. Much of this growth may focus on areas near the WCAs and ENP and could have impacts on water supply, water quality, flood control and wildlife habitat. Dade County has proposed that some extensive wetland areas be purchased and preserved to eliminate the potential impacts of growth near the Everglades.

5. Basin Descriptions.

C-51 (West Palm Beach Canal) Basin. The C-51 basin, totaling 164.3 square miles, is divided by State Road 7 into two subbasins; C-51 east, and C-51 west. Total area of the western portion of the C-51 basin is approximately 79.5 square miles. The eastern portion of the C-51 basin falls outside the Everglades planning area and so this discussion primarily focuses on the western subbasin. The western subbasin extends four miles south of the West Palm Beach canal (C-51) and six miles north, extending from State Road 7 in the east, to WCA-1 and the L-8 borrow canal in the west. Ground elevations range from 13 to 22 feet above mean sea level, sloping from north to south. Sand and muck soils predominate in this basin.

The District's canals and water management structures in this basin have several functions including flood protection and drainage, discharge of water from the L-8 basin to tidal areas, water supply, and water table elevation maintenance sufficient to prevent salt water intrusion. Presently, C-51 provides a less than 1-in-10 year flood protection for the western subbasin. During periods of heavy rainfall, runoff from the highly urbanized eastern portion of the C-51 basin fills the canal to capacity, leaving the runoff from the western part of the basin without an outlet, resulting in flooding of the western area (Water Management Planning for the Western C-51 Basin, March 1984). Without a basin divide structure and pump station west of U.S. 441, the basin will continue to experience flooding problems during 1 in 10 year or greater storms (Cooper and Lane 1988). Land use plans in the western C-51 basin should consider the limited flood protection afforded in this area.

The District in 1987 adopted special basin rules for development in the Western C-51 Basin to require additional, site-specific surface water management for new developments to avoid continued decline of flood protection within the basin. The District also has initiated efforts in cooperation with the U.S. Army Corps of Engineers (USCOE) to design additional flood protection capacity without reliance on direct backpumping into WCA-1, as originally proposed in the 1960s.

The USCOE is finalizing a proposed design to provide additional flood protection in the western C-51 basin. During flood conditions, runoff would be pumped from C-51 to a proposed 1,600-acre retention area, located east of WCA-1 and S-5A, and south of C-51. This area would have the capability of handling a 1-in-10 year flooding event. In rainfall events exceeding the design capacity, water could spill over from the retention area into L-40 canal inside of WCA-1, providing an additional flood outlet area. In some cases, as water levels fall, this excess water could then be transferred back into the retention area or to C-51 Canal.

Perimeter canal (L-40) water quality in WCA-1 generally is poor due to nutrient-enriched agricultural runoff from the Everglades Agricultural Area (EAA). The quality of C-51 water currently is expected to be better than that of the perimeter canal, but would not be pristine because of urban runoff. The possibility of increasing inflows of urban runoff into a National Wildlife Refuge raises concerns. Problems could arise if a rainfall event is severe enough to cause the perimeter canal waters together with the spillover from the proposed reservoir to overflow into the interior wetlands of WCA-1, which presently have very good water quality. In addition to concerns for WCA-1, water quality in C-51 is important because the canal is a source of water for Lake Worth Drainage District canals, which provide recharge to the potable water wellfields in southern Palm Beach County.

All discharges from the western C-51 Basin into WCA-1 should meet the same criteria as provided for other basins in this plan, including the proposed 0.03 mg/l annual average target for phosphorus. Any plans to increase the amount of discharge should also be reviewed for potential hydroperiod impacts on WCA-1.

Within the western C-51 lies the Acme Improvement District, a Chapter 298 district. This District has responsibility for secondary flood protection for the Wellington subdivision and adjacent lands. Acme operates two pumping stations which directly discharge into the L-40, within the boundaries of WCA-1. The District is reviewing water quantity and quality data from the Acme pump stations to determine the current status of these discharges.

Hillsboro Canal Basin. The Hillsboro Canal Basin occupies an area of about 102 square miles and is located in southern Palm Beach and northern Broward counties. It is bounded on the west by the L-40 and L-36 borrow canals, on the south by Wiles and Sample roads, and by the C-15 Basin in the north, and the Intracoastal basin in the east. Excess water from the basin is discharged easterly through the Hillsboro Canal to tidewater. Water is supplied to the basin from WCA-1, WCA-2A (by seepage into the L-36 borrow canal) and from localized rainfall. Water also is supplied from Lake Okeechobee during times of shortages.

Two District canals are located in the Hillsboro Canal basin. The Hillsboro Canal runs from Lake Okeechobee to the Intracoastal Waterway in a northwest to southeast direction and then turns east-west while passing through WCA-1. Flow is normally to the east toward tidewater. The L-36 borrow canal runs along the eastern boundary of WCA-2A. Flow is usually north to the Hillsboro Canal.

The Deerfield Lock, which is being considered for replacement with a modern water control structure, controls water levels upstream, maintains headwater stages to prevent saltwater intrusion to groundwater, and controls discharges to tidewater.

The Hillsboro Canal and Deerfield Lock were constructed prior to the Central and Southern Florida Flood Control Project, with the District assuming operational responsibility from the Everglades Drainage District. The canal and lock were not designed for a particular intensity storm event. Flooding is a concern in this basin, especially in the southwestern area. During severe storms, the Hillsboro Canal flows both east and west. The westward flow may continues for a period of from 36 to 48 hours, causing flooding in the southwestern portion of the basin.

Lake Worth Drainage District (LWDD) canals (located in Palm Beach County) are the major contributors of inflow to the Hillsboro Canal (Cooper and Lane, 1987). Some of the LWDD canals which run north-south do not have divide structures to prevent transfer of water between basins. Water levels in LWDD canals can determine where runoff enters the Hillsboro Canal, either east or west of the Deerfield Lock. The area of land draining upstream or downstream of the lock also varies, depending on stages in LWDD canals. The LWDD also receives water from the Hillsboro in times of shortages using a pump provided by the City of Boca Raton to mitigate groundwater and surface water drawdowns created by that municipality's western wellfields.

Continued rapid growth, especially west of Boca Raton, and in northern Broward County, has raised concerns about the Hillsboro Canal's capacity to deliver 1 in 10 year flood protection levels. Plans to construct a backpumping station discharging into WCA-2A have been discussed since the 1960s, but are not considered a preferred option because of environmental concerns over discharging urban runoff into the Everglades. Backpumping alternatives, including plans for direct discharges and indirect discharges via a detention area, are being evaluated along with other options by the USCOE in an on-going study started in 1988.

The first-phase or reconnaissance study of flood protection concerns in the Hillsboro Canal basin, has recently been completed and resulted in a recommendation that additional investigations of the alternative strategies be continued in a three-year federal feasibility study (USCOE, 1989). At the conclusion of the first phase, only one option, canal widening and associated work, was found to have a positive cost-benefit ratio. However, the USCOE reported that other options, including discharges to the WCAs, may become feasible with additional refinement and analysis. The conclusion of the study and analysis phase of USCOE planning procedures will take several years. Implementation of final recommendation is considered to be five to ten years away.

Any recommendation to create new discharges into the WCAs should require that these discharges meet the water quality and hydroperiod goals of this plan.

The Palm Beach County Solid Waste Authority is purchasing land at the juncture of the Hillsboro Canal and L-40 for a new landfill. This site was chosen out of fifteen possible locations. The landfill project has two phases. The first phase of the project has been approved, with the landfill being designated as Class III. This means that only trash such as construction debris and discarded vegetative material can be brought to the site. No household or toxic materials would be permitted under the current phase one proposal. The second phase, which has not been approved, is the construction of a resource recovery area and incinerator. The District's analysis of the proposal suggests that with proper design, the landfill may pose no threat to groundwater and the surrounding wellfields of the Hillsboro Canal basin. Opposition to the landfill have been raised by area residents, and by U.S. Fish and Wildlife Service officials managing the adjacent wildlife refuge (WCA-1).

C-14 (Cypress Creek Canal) Basin. Only a small part of the C-14 basin is included in the Everglades SWIM planning area. This basin is 59 square miles and is divided into western (25 square miles) and eastern (34 square miles) subbasins. The boundary between the two subbasins is Farm Road which is two miles west of State Road 7. The western boundary of the western subbasin is the L-36 borrow canal which is also the eastern boundary of WCA-2A and 2B. The north boundary of the west C-14 subbasin is Wiles Road. The south boundary is the western C-13 subbasin.

Canals and structures in the C-14 basin have several functions, including flood protection and drainage; water supply to the C-14, C-13, and Pompano Canal basins during periods of low flow; moving excess water from WCA-2A west to tidewater, controlling seepage from WCA-2A, and maintaining groundwater levels sufficient to prevent saltwater intrusion. Excess water from WCA-2A is discharged to the canal and to tidewater. Excess water from the basin is discharged to C-14 and released to tidewater. Water supply to this basin occurs by seepage from WCA-2A and rainfall.

A pump station controlled by the North Springs Improvement District (NSID), a Chapter 298 special district, is located next to the District's S-38B control structure. This NSID can discharge excess stormwaters into WCA-2A. A review of the quality and quantity of water passing into the WCAs from this pump station is recommended. Generally, only the extreme western portion of the basin adjacent to the levees, and those areas drained by the NSID directly impact of the WCAs.

C-13 (Middle River Canal) Basin. The highly urbanized C-13 basin is located in eastern Broward County and has a total area of 39 square miles. It is divided into an eastern basin of about 9 square miles, and a western basin of about 30 square miles. The boundary between these subbasins is a north-south line which runs through S-36.

The C-13 basin is bordered by the C-14 and North Fork New River basins on the north, the North New River Canal (NNRC) West and C-12 basins on the south, the L-36 borrow canal and C-42 on the west, and the Intracoastal Waterway and North Fork Middle River basins on the east. This basin includes a major portion of the city of Plantation and the C-13 Canal is an important facility for provision of flood and water supply protection for the city. Excess water in the C-13 basin is discharged to the north and south forks of the Middle River Canal and to the North New River Canal basin. Some C-13 water may be discharged into the WCAs via the G-123 backpumping station in the NNRC basin.

North New River Canal Basin. The North New River Canal (NNRC) basin is located in eastern Broward County and has an area of about 30 square miles. It is divided into an eastern (7 square miles) and a western (23 square miles) basin. The basin is bounded on the south by the North New River Canal, on the west by the L-35A borrow canal, on the east by State Road 7, and on the north by the C-13 basin. Excess water from the NNRC basin can be discharged to tidewater through Sewell Lock, or can be pumped to WCA-3A from the NNRC through the G-123 pumping station. Supplemental water is supplied to the basin from WCA-2A.

The NNRC was originally excavated to drain the Everglades and to provide a transportation route from Lake Okeechobee to the eastern coast. The SFWMD took over management of the canal from the Everglades Drainage District. Presently, the canal and Sewell Lock provide protection for a 1-in-25 year storm event. A 1-in-50 year storm event will probably cause some flooding in the western part of the basin. (Cooper and Lane, 1987)

C-11 (South New River Canal) Basin. The C-11 basin is located in south central Broward County and has an area of approximately 104 square miles. The basin is divided into an eastern basin (23 square miles) and a western basin (81 square miles). The eastern portion of this basin falls outside of the Everglades planning area. The western C-11 basin is bordered by WCA-3A (L-37) and 3B (L-33) on the west, by State Road 84 (I-75) on the north, Hollywood Boulevard on the south and by a north-south line which runs through S-13A, perpendicular to C-11.

The C-11 Canal runs east-west through the basin, adjacent to Griffin Road, and discharges into the south fork of the New River Canal in the eastern portion of the basin. The S-9 pump station, built in the late 1950s, is a major component of flood protection for the region, discharging excess stormwaters to WCA-3. The three large engines which drive the pumps were recently replaced.

The western C-11 basin is undergoing development and is being quickly urbanized, especially since the construction of the Sawgrass Expressway to the north and the southern leg of Interstate 75. Some agricultural uses still occur in the western basin. The urban development pressure forces land planners to take a second look at land which was formerly considered to be uninhabitable. Construction of new secondary canals and deepening of already existing secondary facilities could drain existing wetlands. These wetlands presently provide groundwater recharge. Also, continued development carries associated water quality and quantity concerns due the possibility of contaminated runoff from lawns (nutrients from fertilizer), and roadways (heavy metals, polynuclear aromatic hydrocarbons), as well as increased runoff from other impervious surfaces entering surface waters and the shallow aquifer. Nutrients and other urban pollutants associated with increased development could be exported to the WCAs in the backpumped water at the S-9 facility. The District is reviewing water quality information for the C-11 basin. The C-11 basin is currently discharging water with phosphorus concentrations that are slightly better than the recommended level of 0.03 mg/l target for annual average phosphorus concentrations. Because of the continued growth and because the water quality is near the recommended target, the area should be closely monitored to assure that phosphorus levels do not increase above the current average. Monitoring for other substances that may impact the WCAs should be increased.

A narrow strip running north-south between U.S. 27 and WCA-3A and WCA-3B, and extending in to the C-9 Basin, was recently nominated by Broward County for consideration in the Save Our Rivers program. This area, the so-called Everglades Buffer Strip, is largely undeveloped and contains extensive, although impacted, wetlands. One reason that this land was recommended for purchase is to buffer the Everglades from urban development. Another reason that this land is recommended for public purchase is that it receives extensive amounts of groundwater seepage out of the WCAs. Due to these hydrologic conditions, suitable flood protection for urban or other development cannot be assured in this area.

C-9 (Snake Creek) Basin. The C-9 basin is located in southern Broward and northern Dade counties and is approximately 98 square miles in area. The basin is divided into to two subbasins (east, 45 square miles, and west, 53 square miles) by Flamingo Road in Broward County and NW 67th Avenue in Dade County. -C-9 flows west to east, emptying into Dumfoundling Bay.

The western subbasin is susceptible to flooding due to relatively low ground surface elevations. Major storms can cause a reversal of flow in the C-9 basin due to rapid runoff in the eastern portion of the basin. Seepage from WCA-3B, which is intercepted by the L-33 borrow canal, is the major source of water in this basin. Excess water can be held in the area between L-33 and U.S. 27, the southern portion of the Everglades Buffer Strip. This stored water can be released, as needed, through S-30. Some portions of the basin are experiencing urban development and the area is experience major growth during the next two decades. The basin has been studied for water supply backpumping, but no action has been taken to recommend such a plan.

C-4 (Tamiami Canal) Basin. The C-4 (Tamiami) Basin covers an area of about 60.9 square miles in Dade County, west and southwest of the city of Miami. The basin is bounded on the east by the West Dade Expressway, on the west by WCA-3B (L-30), on the south by the Tamiami Trail (U.S. 41), and on the north by the Miami Canal basin (C-6). The C-4 area is poorly drained and has flat topography, rising 5.5 to 6 feet above mean sea level. Due to the highly permeable shallow aquifer, seepage from the WCA is an important source of freshwater recharge.

The C-4 basin is prone to flooding and presently has little flood protection. A floodplain study has been recommended for this area before development occurs. Until detailed land use studies are completed, recommended residential land use is limited to one unit per five acres. At this time, the USCOE is determining feasibility of backpumping runoff from the western portion of the C-4 basin, along with the northern portion of the C-2 basin to WCA-3B. A multi-phase project to boost Metro-Dade water supply is underway in this basin. A new canal presently under construction will convey water to the Dade-Broward Levee borrow canal and to the borrow canal east of the West Dade Expressway, which will subsequently discharge waters into C-4. Phase I (from S-337 south) of this project is scheduled to be completed next year. Construction of Phase II (additional excavation south) will begin next year. The status of Phase III, the completion of the canal south to C-4, is undetermined at this point. This new canal will assist in the recharge of the Dade County's Northwest Wellfield, which is located in the northwest portion of the C-4 basin. This newly constructed canal will also create a groundwater divide between the wellfield and a problem-plagued landfill that is located between C-4 and C-6, preventing possible groundwater contamination by the landfill.

The Pennsuco area of the C-4 basin, about 11,962 acres of wetlands, is currently included in the Save Our Rivers, Five Year Plan as a category B project. This designation means that the parcel qualifies for the Save Our Rivers program, but is considered to be lower priority than Category A projects. If landowners contact the District for possible divestment, the District will attempt to secure the land as a gift or at a bargain rate. In accordance with the Northwest Wellfield Protection Plan, adopted by Dade County in 1985, allowable land use in the this area of the C-4 basin includes limestone quarrying, public institutional uses, communication facilities, recreational uses, rural residences (one unit per five acres), and seasonal agriculture. Melaleuca has impacted the area, with the infestation in the southern third considered to be out of control and probably irreversible. The middle third of the basin is heavily infested and will require extensive treatment for control. The northern third of the C-4 basin is lightly infested. There is a proposal to extend State Road 836 through the basin. The alignment of this proposed extension may impact existing wetlands and encourage secondary development in an area of poor flood protection.

The location and operation of Dade County's western wellfields is of concern for the Everglades plan. A primary concern is due to the substantial increases in the water consumption rates projected in the Metro-Dade County Comprehensive Plan. In the past, District staff has strongly advocated the institution of consumer-oriented demand programs for water conservation. However, such a policy has not been implemented. Dade County planning staff have determined that, in the next ten years, an additional area of six square miles will be needed to accommodate County growth. This growth will most likely occur in a parcel of land within the C-4 basin and an area south of it. Development that occurs in the "short hydroperiod wetlands" in this basin, which are directly related to wildlife resource protection and aquifer recharge is expected be an issue.

D. BASINS WEST OF THE WATER CONSERVATION AREAS.

1. Basins Included.

The western basins of the Everglades SWIM planning area include the C-139 basin, the Feeder Canal basin, the L-28 Interceptor basin, and the L-28 Gap basin.

2. Basis for Inclusion.

Relation to the Everglades. Each of these basins, including areas northwest of the WCAs, discharges into WCA-3A via structures or gaps in the area's western levee. Inflows from the western basins enter WCA-3A through the S-140, S-190, and G-155. Pumping Station S-140 is located north of Alligator Alley/ I-75. It discharges excess water from L-28 into WCA-3A. S-190 is a gated spillway in the L-28 interceptor canal. This structure prevents overdrainage of the East and West Feeder canals by maintaining adequate water levels upstream. G-155 is located in the gap between L-4 and the L-4 extension located at the northwest corner of WCA-3A. It permits flow from the L-3 borrow canal to WCA-3A, and prevents overdrainage by maintenance of upstream water levels. Another outlet is planned to discharge excess water into Rotenberger, but water quality has been identified as a concern by the District and the FGFWFC. Moreover, much of Rotenberger still remains in private ownership

3. Land Use.

SFWMD land use and land cover data for the four basins in this portion of the planning area are summarized in **Table 40.** Agriculture is the dominant land use in the C-139, Feeder Canal and L-28 Interceptor basins. The remaining land cover in these three basins is predominately wetlands and forested uplands, while the L-28 Gap basin consists almost entirely of wetlands (98%). Urban land uses occupies 4% of the C-139 Basin and less than 1% of the remaining Basins.

Table 40. Generalized 1987/1988 Land Use/Land Cover Types and Acreages by Watershed for the Western Basins of the Everglades SWIM Study Area.

Basin	Land Use Type							
	Agriculture, acres (% basin)	Urban, acres (% basin)	Rangeland, acres (% basin)	Forested, acres (% basin)	Wetlands, acres (% basin)	Water, acres (% basin)	Barren Land, acres (% basin)	Totals, acres (%)
C-139	122,776 (61.8)	8812 (4.4)	602 (.3)	16,737 (8.4)	49,491 (24.9)	296 (.1)	8 (.004)	198,722 (99.9)
Feeder	35,462 (49.0)	551 (.8)	--	9566 (13.2)	26,563 (36.7)	60 (.08)	122 (.2)	72,324 (100.0)
L-28 Gap	433 (.3)	1110 (.9)	--	570 (.4)	126,312 (97.9)	165 (.1)	367 (.3)	128,957 (99.9)
L-28 Interceptor	36,187 (50.4)	258 (.4)	432 (.6)	29 (.04)	34,649 (48.3)	--	235 (.3)	71,790 (100.0)

The areas immediately west of WCA-3 include the Seminole Indian Tribe of Florida and the Miccosukee Tribe of Indians of Florida. These areas include extensive private holdings which traditionally have been used for cattle operations on either native range lands or improved pasture. The basins west of WCA-3A are undergoing rapid intensification of agricultural development. During the 1980s, native range lands, improved and unimproved pastures have been undergoing conversion to citrus, sugar cane or other agricultural use.

4. Water Management Related Issues.

Indian Lands. The locations of reservations of the Seminole Indian Tribe of Florida and the Miccosukee Tribe of Indians of Florida are important to the Everglades SWIM Plan. The SWIM plan should not impact water supply and flood protection of tribal lands adjacent to the WCAs. Tribal lands within the WCA system should be restored and maintained as natural Everglades habitat for the benefit of the Tribes and the Everglades ecosystem.

Flood Protection. L-1, L-2, and L-3 were constructed to protect the western boundary of the EAA. Historical flows from the west were interrupted and flooding west of these levees occurred. Originally, the USCOE proposed to construct a canal and levee from Lake Hicpochee in Glades County to WCA-3A. The project was altered and is referred to as the Modified Hendry County plan.

The Montura Ranch Retention area (Central County Water Control District) located in northeastern Hendry County, is connected to the north-south L-2 borrow canal by way of the newly constructed L-2W and borrow canal. When flooding problems occur, it is possible to pump water into the retention area. Two additional canals (L-1E and L-3E) have been designed to alleviate flooding in the C-139 basin. Both of these canals connect to the Miami Canal. The L-1E connects L-1 and the Miami Canal north of the Bolles Canal, and L-3E is proposed to connect will follow the northern boundary of the Rotenberger tract between L-2 and the Miami Canal. The L-3E has not been constructed.

Water Quality. There has been very little specific study of the western basins. The water quality data for the L-3 borrow canal indicate that the water sampled has relatively high concentrations of phosphorus. The source of phosphorus is unknown, however it has been speculated that it could be attributed to livestock operations in the basin or the result of fertilization of sugar cane, citrus or other crops on sandy, infertile soils west of the EAA. As land is managed more intensively, the water quality in these basins is likely to decline, and additional monitoring is warranted. One of the original projects recommended in the Everglades SWIM Plan is to undertake assessments of the western basins in Hendry and Collier counties to better document existing land use and water-related issues, including identification of the sources of the nutrient problem in the L-3 basin. Also, other District studies underway will help better understand agricultural water-resource issues in this and other western basins.

Wildlife Resources. Western portions of these basins are utilized by the Florida panther and other wildlife. As tens of thousand of acres of citrus are planned and planted, endangered wildlife such as the Florida panther, the wood stork, crested caracara, and the sandhill crane as well as other wildlife may be forced from their native ranges. A study is currently underway to evaluate the effects of citrus conversion on wildlife habitat.

E. EVERGLADES NATIONAL PARK STUDY AREA

1. Introduction and Overview.

Historically the Everglades system comprised approximately 3,600 square miles (Davis, 1943a). In 1943, Davis stated that "The canals and other drainage construction have caused notable changes in water, soil, and vegetational conditions of large areas in the Everglades." and continued to say, "The proper use of these Everglades still remains one of Florida's greatest problems of land utilization." Beard (1938), in a reconnaissance report on the proposed Everglades National Park (ENP), reports on damages due to drainage, canals, impacts of agriculture and effects of non-native plant species on vegetation of the region that was to become the Park. "Primitive conditions have been changed by the hand of man, abundant wildlife resources exploited, woodland and prairie burned and reburned, water levels altered, and all the attendant, less obvious ecological conditions disturbed" (Beard, 1938).

The problems currently threatening the Everglades region and ENP are not new, have been recognized and discussed for years, and stem from the regulation of water and its timing, delivery patterns, flow, and quality (Beard, 1938; Davis, 1943a; Schomer and Drew, 1982; USCOE, 1985; Wagner and Rosendahl, 1987; Ogden *et al.*, 1987; and Gunderson *et al.*, 1987). These problems originate from outside of the Park boundaries. Problems involving the Park and the historic southern Everglades system also are linked to development and land use in Dade County. The Park is defined by an artificial jurisdictional boundary that has been imposed on a natural system whose hydrological and water quality characteristics are closely tied to water resources originating outside its boundaries. The area originally proposed for Park acquisition included much of western Dade County, the area known as the East Everglades, Barnes Sound and northern portions of Key Largo, the western portion of all the keys that currently border the park, Caryfort Reef to the edge of the reef tract, ~5 mi. from the shore (Beard, 1938). If this system had been acquired and incorporated as the original ENP as proposed, many of the problems currently facing the Park would either not exist, or to a large degree, such problems as water distribution, timing, and quality would be much easier to solve. The boundaries of what is currently ENP do not comprise a functional hydrological unit. They are missing the head waters of Taylor Slough, the head waters of Shark River Slough, the main area of land upstream of northeast Florida Bay, and the rockdale lands that historically comprised the short hydroperiod wetlands that were continuous with other areas that historically served as foraging areas for wading birds.

Fifty one years ago, Beard (1938) stated "The most important problem to be settled before the Everglades National Park is established is that of restoring water levels." and further "This flow of water was not confined to the rainy season alone, but it had a greater volume then. The land is flat and drainage through the porous rock structure and marl soil was slowed down." He also discussed one of the early expeditions which used canoes to cross the glades during the dry season, something which at the time of his writing was not possible.

Currently water management practices have resulted in alteration of historic flow patterns, compartmentalization and isolation of portions of the system, decrease in the total volume of water per area, altered timing of flow events, and changes in chemical constituents (i.e., specific conductivity and major ions) of inflow waters. These changes have resulted in the following well-documented problems: decreased productivity of marsh systems, reduced aquatic diversity of freshwater systems, reduced nesting and reduced nesting success of wading birds, alteration in marsh community composition, encroachment of exotic plants and animals, and artificially-induced, extreme fluctuations in salinity within Florida Bay. In addition to these problems there are additional areas of concern that are less well understood. These problems include: potential hydrologic links between various portions of the area such as Taylor and Shark Sloughs, hydrologic connections to Florida Bay, water management impacts on Florida Bay, the effects of freshwater inflows on the salinity of northeast Florida Bay, potential impacts of loss of freshwater flows, hypersalinity and seagrass die-off in Florida Bay, the impacts of changes in salinity and habitat on the use of Florida Bay as juvenile and rookery areas for many marine animals, and the actual volumes of water necessary to establish viable habitat for the native flora and fauna that the park was originally designed to protect. Some major changes have been proposed and examined to date to restore portions of the system as well as to identify information needed to refine issues that are presently not well defined.

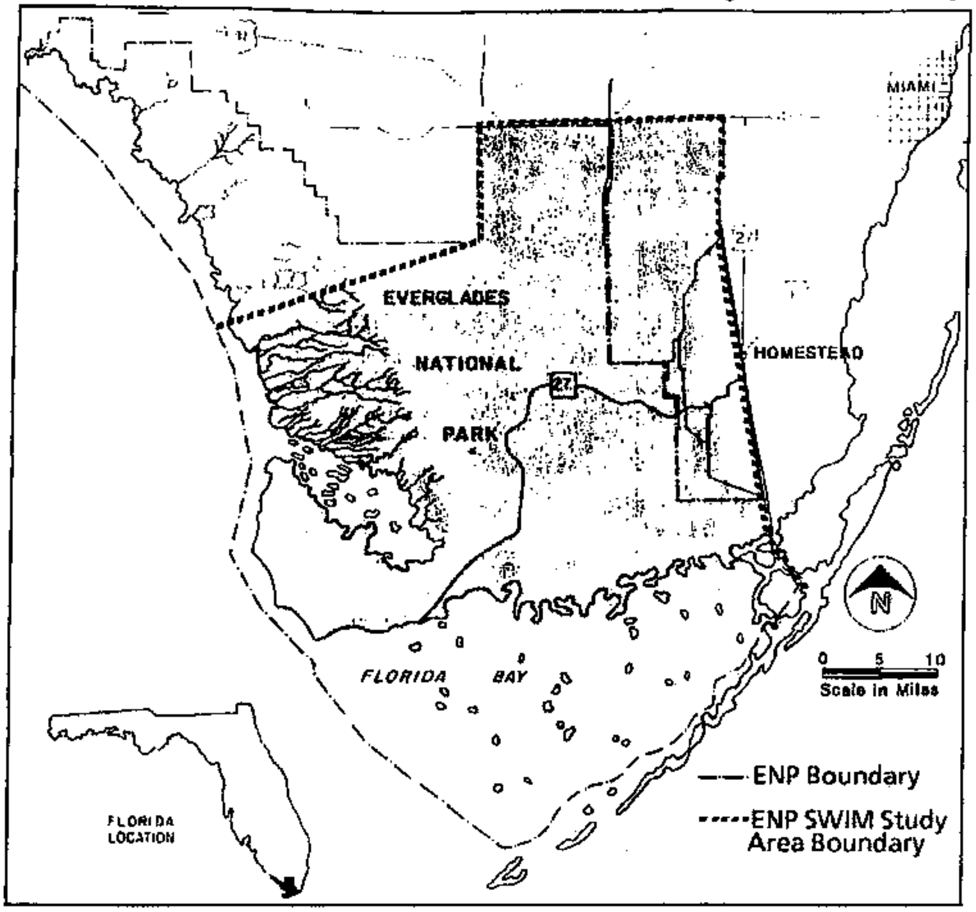
Two major water management changes are now under consideration by the USCOE and the South Florida Water Management District (SFWMD). These are included as portions of the Shark River Slough General Design Memorandum (GDM) report and the C-111 canal GDM. These two projects by the Corps of Engineers are designed to redistribute water more naturally into historic flow channels and increase the amount of water available to both the western (Shark Slough) section and the eastern (Taylor Slough/C-111 basin). The park has also expressed concern over water delivery problems to the Big Cypress Basin, and the Water Conservation Areas as well as Everglades National Park. The primary focus of the Shark Slough GDM is rewetting the historic portions of Shark Slough that are currently cut off from the system by construction of the L-67 extension canal. Other recommendations from the current park research staff include reconnecting Water Conservation Areas 3A and 3B with each other and with the Park, and preventing any further segmentation of the system into disjunct units by drainage canals and levees within the Park or the conservation areas.

2. Boundaries.

The approximate boundaries of the ENP SWIM Planning Area are shown in **Figure 40**. The northern boundary is defined by Tamiami Trail (U.S. Route 41). From the Tamiami Ranger Station, the planning area follows the Everglades National Park/Big Cypress National Preserve (ENP/BCNP) boundary south. At the location where the ENP/BCNP boundary turns to the west, the planning area boundary angles to the southwest toward Key McLaughlin following the approximate basin flow pattern of the Shark River Slough. Those portions of the ENP north of this planning area boundary will be included in the Big Cypress SWIM planning area, when the SFWMD establishes a higher priority for SWIM planning efforts in that area.

The ENP SWIM Planning Area is bounded on the east by the L-31N Canal and levee system, and the C-111 Canal. Areas east of the L-31 levees and the area within the C-111 Basin lie within the Biscayne Bay SWIM Planning Area. To a limited extent, conditions within the western margin of the C-111 Basin are addressed as components of the Everglades sub-section because of the role played by the South Dade Conveyance System in water deliveries to the ENP. The boundary between the upland ENP portion of the planning area and estuarine Florida Bay planning area is arbitrarily defined as the waterward extent of the mangrove fringe. The upland area includes Cape Sable while the mangrove islands of Whitewater Bay and Florida Bay are included in the estuarine portion. The East Everglades/C-111 Basin and the

Figure 40. Everglades National Park SWIM Study Area Boundary.



Source: CH_2M Hill (from Rosendahl and Rose,1979)

Florida Bay Basins are included as separate sections of the ENP Planning area to more adequately address the specific resources and problems of these regions.

3. Physiography.

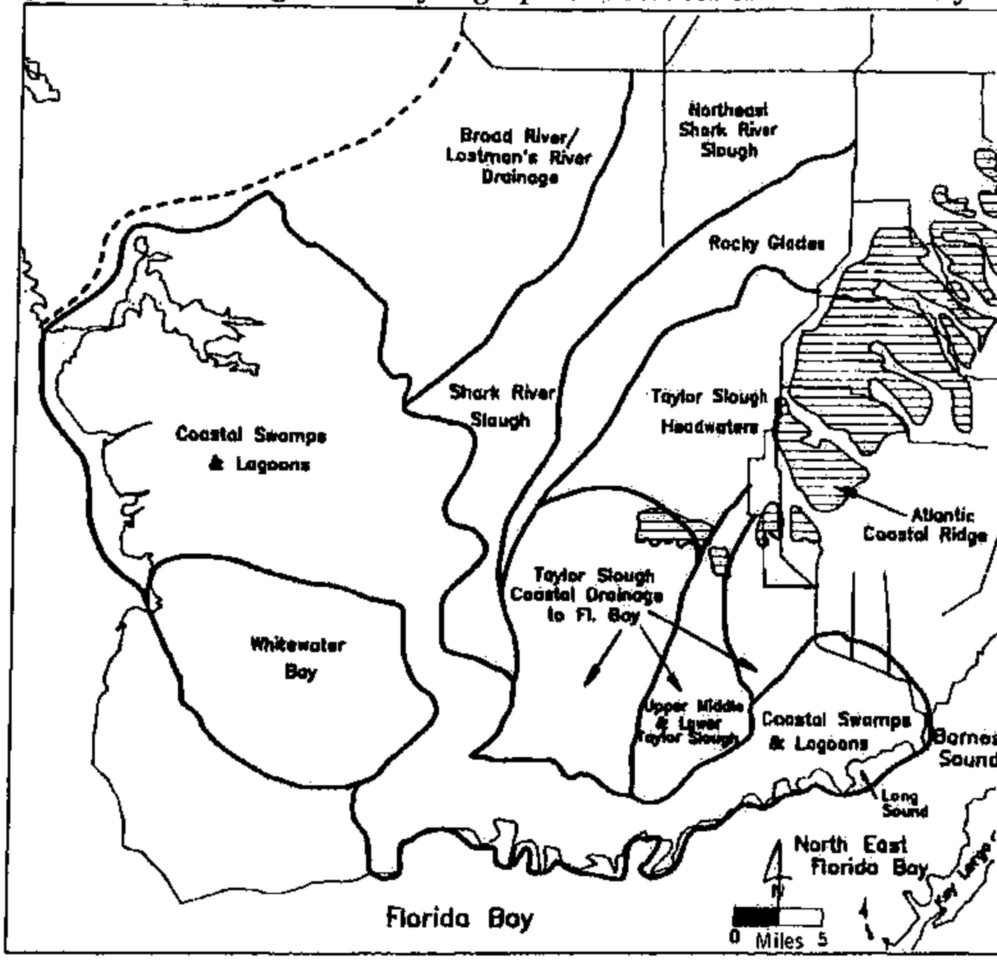
Based on previously published records (Davis, 1943a; Puri and Vernon, 1964; White, 1970; Craighead, 1971), Schomer and Drew (1982) divided the Everglades into two physiographic areas, the Lower Everglades Basin and the Taylor Slough/Florida Bay Basin.

Lower Everglades Basin. Within the Lower Everglades Basin, Schomer and Drew (1982) recognized five physiographic subzones as depicted in **Figure 41**:

* Shark River Slough
* Rocky Glades
* Broad River/Lostmans River
* Coastal Swamps and Lagoons
* Cape Sable

Shark River Slough. Shark River Slough is a broad southwesterly trending arc of continuous wetland, interspersed with numerous tree islands. Expansive transitional areas of slightly higher bedrock elevation distinguish its northwestern and southeastern boundaries. The slough occupies the center of the Everglades

Figure 41. Hydrologic and Physiographic Provinces of the ENP Study Area.



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

trough which may be described as a wide, slightly concave depression in the underlying limestone (White, 1970).

Rocky Glades. Southeast of Shark River Slough lies a transition area known as the Rocky Glades or Rocklands (Davis, 1943a). The name Rocky Glades is derived from the character of the limestone rock that lies exposed at the surface. The limestone (also called pinnacle rock) is comprised of rock-hardened bryozoan colonies laid down when the area lay beneath sea level during the Pleistocene.

The Rocky Glades form a thin transitional area between the Shark River and Taylor Sloughs. Geologically, the Fort Thompson Formation underlies much of the Everglades trough as a surface bedrock feature, while the back slope of the Atlantic Coastal Ridge (Miami Limestone) forms the surface rock for the area farther east. These bedrock features also make the Rocky Glades a hydrologic transition between the Shark River Slough drainage to the southwest and the Taylor Slough drainage to the south.

Broad River/Lostmans River. Northwest of Shark River Slough, the bedrock of the Everglades trough rises gradually toward the Big Cypress Spur, an extension of the Immokalee Rise (Puri and Vernon, 1964; White, 1970). These latter features generally define the Big Cypress Basin. The area of freshwater wetlands located between the Everglades trough and the Big Cypress Basin is known as the Broad River/Lostmans River Drainage.

Like the Rocky Glades, subtle differences in hydrology, hydroperiod, and geology distinguish this area from Shark River Slough. The Miami Limestone virtually disappears when a veneer of Pamlico sands of the late Pleistocene encroaches upon the Fort Thompson Formation, the bedrock of the Everglades trough (Cooke, 1945).

Coastal Swamps and Lagoons. Puri and Vernon (1964) referred to the low mangrove and salt marsh areas at the lower end of Shark River Slough as reticulated coastal swamps. These coastal swamps and lagoons extend from the upland limit of periodic salt water influence to the Gulf of Mexico, a distance of about 10 to 25 miles (16 to 40 kilometers). According to Schomer and Drew (1982), the prominent features that delineate the area are:

* salt marshes, which lie relatively upland
* mangrove forests that lie in vast wetland expanses and along shorelines; and
* "back bays" or lagoons--distinct physiographic features that become more prominent north along the coast.

The coastal swamps and lagoons receive most of the surface runoff from the Everglades. Prior to the recent Flandrian sea level rise of the Holocene epoch, a larger area was inundated by freshwater. As surface waters flowed over this area, differential solution of the less-resistant bedrock limestone formed freshwater channels (Schomer and Drew, 1982). Freshwater runoff increased the various peat-and/or marl-forming environments. As sea level rose to its current level, some areas of underlying peat eroded and oxidized, leaving an anastomosing network of lagoons and "back bays" (Spackman *et al.*, 1964; White, 1970).

The largest and most conspicuous of these lagoons is Whitewater Bay. The drainage pattern along the northern edge follows the numerous southeasterly trending channels of Watson River, North River, and Roberts River. The bay to the southeast is confined by an extension of the Atlantic Coastal Ridge that terminates in the "Cape Sable High" (White, 1970).

Where the main flow of the Lower Everglades Basin drains to the Gulf of Mexico, conditions are less favorable for the formation of lagoons or back bays (White 1970). Consequently, a wide area of coastline north of Whitewater Bay contains only one small lagoon-like body of water (Tarpon Bay in the Harney River) (Schomer and Drew, 1982).

Cape Sable. Cape Sable is one of the most distinctive features of the southwestern tip of Florida. White (1970) claims that the cape overlies a degenerate westerly extension of Miami Limestone of the Atlantic Coastal Ridge. He refers to the terminal end of this extension as the "Cape Sable High."

It is believed that the beaches of Cape Sable first formed as a result of a shallow submarine scarp cut into bedrock (White, 1970). The coastal prairies behind the beaches are composed of a succession of troughs and low dunes (Craighead and Gilbert, 1962). On the upland side of these prairies, the highest elevations support a continuous ridge of hammocks (Craighead, 1971). A series of shallow ponds, the largest of which is Lake Ingraham, extend from the north of the middle Cape to Flamingo. Craighead (1971) considers these ponds remnants of former open waters that have not been completely filled in by marl and peat.

Taylor Slough/Florida Bay Basin. Schomer and Drew (1982) separate the Taylor Slough/Florida Bay Basin into five physiographic subzones:

* Taylor Slough Headwaters
* Upper, Middle, and Lower Taylor Slough
* Taylor Slough Coastal Drainage
* Coastal Swamps and Lagoons
* Florida Bay

These subzones are depicted in **Figure 41**. A description of the Taylor Slough headwaters is provided in the C-111/East Everglades Section of this report. The next three subzones are described in the following sections; Florida Bay is described in detail under the Florida Bay Section of this report.

Historically, sheet flow through the Everglades followed a south by southwest curve, as outlined by the arc of Shark River Slough (**Figure 41**). Some of the sheet flow, however, has been transverse to the main axis of the Miami Rock Ridge, the Everglades Keys, and the Rocky Glades. Erosion of the thin layer of marl soils and solution of the underlying Miami Oolite created a solution-riddled landscape cutting across the limestone toward Taylor Slough.

<u>Upper, Middle, and Lower Taylor Slough</u>. The northern boundary of this physiographic subzone is located where L-31W intersects the main channel of Taylor Slough (Olmsted *et al.*, 1980). This area is referred to by Olmsted *et al.* (1980) as Upper Taylor Slough. It is a well defined 3.4-mile (5.5-kilometer) long segment running from the intersection of the slough and the canal levee structure L-31W south to State Road 27 (Anhinga Trail). Middle Taylor Slough is defined as the segment of the slough from State Road 27 south 4 miles (6 kilometers) (Olmsted *et al.* 1980). Lower Taylor Slough is defined as the segment lying south of this point and draining to Florida Bay.

<u>Taylor Slough Coastal Drainage</u>. Schomer and Drew (1982) described the areas immediately east and west of Taylor Slough and north of the coastal swamps. This area is referred to as the Taylor Slough Coastal Drainage. The limestone ridges, Long Pine Key and Everglades Keys, that run west/southwest from upper Taylor Slough form a barrier inhibiting sheet flow from Shark River and the lower Rocky Glades. This forms the northern boundary of the drainage basin, from which surface waters flow south either into Taylor Slough or overland to the east into Florida Bay.

The area south of the Everglades Keys is largely dominated by muhly grass prairies. The Hole-in-the-Donut, located nearly in the middle of this area, was formerly a significant agricultural tract. This forms the southeast fringe of Long Pine Key.

<u>Coastal Swamps and Lagoons</u>. In the coastal area west of Taylor Slough, Puri and Vernon (1964) distinguish two physiographic provinces lying within the Taylor Slough drainage basin. The first of these provinces refers to the series of lagoons from Seven Palm Lake to West Lake. A broad continuous strip of land covered by coastal prairie occupies the area north of these lagoons, running southeast to the mangroves bordering Madeira Bay. The northern border of these lagoons roughly corresponds to a partial barrier between fresh and saline waters known as the Buttonwood Embankment (Craighead, 1971). A distinct band of pioneer red mangrove (*Rhizophora mangle*) occurs 2 to 5 miles (3 to 8 kilometers) inland of this barrier (Schomer and Drew 1982).

Reticulate Coastal Swamps, the second province distinguished by Puri and Vernon (1964) in this region, correspond to the more saline black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*) communities which occupy the areas south to Florida Bay.

West of lower Taylor Slough the coastal swamps and lagoons are characterized by a series of lakes or lagoons fringed by mangroves, with some tropical hardwoods toward the eastern end (Schomer and Drew, 1982). South of these lagoons toward Florida Bay the area is dominated by red, black, and white mangroves, buttonwood, and prairies of salt tolerant vegetation (Russell *et al.*, 1980). On the eastern side of Taylor Slough the coastal lagoons are less prominent, and the surface drainage is better defined. This hydrologic structuring leads to a land and vegetation pattern that radiates out from the surface drainage pattern (Schomer and Drew, 1982).

4. Geologic and Topographic Structure of the Study Area.

Holocene Sediments of the Lower Everglades. Holocene sediments in the Lower Everglades and Taylor Slough are the result of a seasonal abundance of rainfall and a warm subtropical climate, which over the last 5,000 years have promoted a highly productive vegetation and an indurated surface veneer of the periodically-exposed limestone. The hardened surface has led to retention of water and growth of wetland vegetation. Together, these conditions create an ideal environment for the formation of alternating layers of organic peat and calcitic muds. Holocene sediments in the coastal areas reflect a more pervasive marine influence.

Gleason *et al.* (1984) consider all Holocene sediments and soils of south Florida mainland to be of the Lake Flirt Formation. The distribution of surface sediments and soils in south Florida closely follows bedrock geology and hydrology (Davis, 1943a; Parker and Cooke, 1944; Davis, 1946; Gleason *et al.* 1984). The underlying bedrock geology is characterized by two troughs corresponding to Shark River and Taylor Sloughs. These distinctive bedrock features are masked in surface topography. The subsurface features are flattened out by peat accumulation and the deposition of fresh- or brackish-water calcium carbonates.

Within the lower Everglades (Shark River Slough) and Taylor Slough areas, there are two major divisions of Holocene sedimentary sequences:

* Areas in which geologic core borings to Pleistocene bedrock reveal no brackish water sequences of marl or peat.
* Areas in which core borings indicate inundation by brackish, marine conditions at some time in the recent past.

According to White (1970), a critical factor in determining where fibrous peat accumulates in south Florida is the nature of the base upon which it rests. Peat occurs commonly over limestone and rarely on silica sand. This association supports the concept of an Everglades trough cut by solution. Fibrous peat may accumulate on limestone because the limestone can be dissolved down to the water table. In contrast, the surface of silica sand cannot be so readily reduced because it is not lowered by solution.

Sediment accumulation in the Everglades area closely parallels the bedrock geology and historical hydrology (Cohen, 1989). Two troughs corresponding to the Shark River Slough and Taylor Slough run through the study area, and it is along these troughs that the greatest thicknesses of Holocene sedimentary sequences have developed. Extensive accumulations of peat and fresh or brackish water calcium carbonate have tended to smooth over these underlying troughs, and today the surface topography within the study area is virtually flat.

Holocene Sediments of Taylor Slough. Holocene sediments in the western Everglades and Taylor Slough areas are the product of case hardening of the periodically exposed limestone rock, the retention of surface freshwater, and the luxuriant growth of wetland vegetation. These conditions have led to the production of alternating layers of organic peat and calcitic mud throughout the area. Cohen (1989) differentiated nine different types of peat from the Everglades and coastal swamps of south Florida. The most significant types of peats seen in this study area are those formed in mangrove, salt marsh, and brackish water habitats; however, the precise mixture of the vegetative and environmental factors dominating peat formation at any given spot have alternated over time with rising and falling sea level.

The distribution, origin, and stratigraphic relationships of the Holocene sediments in the Taylor Slough are presented by Gleason (1972) and summarized by Gleason *et al.* (1984). Six distinct stratigraphic groups are recognized. The summary of the six groups presented below follows Schomer and Drew (1982).

Group A. Composed exclusively of peat, Group A is located in the deepest central portion of the slough. Alternating layers of water lily and sawgrass peats reflect changes in the surface water levels and hydroperiods, presumably a result of climatic and sea level fluctuations. Gleason *et al.* (1984) believe the entire central depression of Taylor Slough is probably underlain by this continuous peat substrate down to the oolitic bedrock. The alternating but continuous record of peat suggests that this portion of the slough was wet continuously during the Holocene.

Group B. Located on both the western and eastern margins of the slough, Group B is composed entirely of calcite. Calcite, produced through the action of blue-green algal mats that extend over much of the exposed limestone, constitutes the "marl prairie" communities to the east and west of Taylor Slough. The ongoing deposition of calcite is believed analogous to the conditions that produced the strata of the Lake Flirt Formation. The continuous calcite strata in these areas suggest the recent environment has remained fairly constant.

Group C. Located in the eastern margin of the slough and running parallel to its axis, Group C consists of an upper layer of calcite underlain by alternating layers of peat. Gleason *et al.* (1984) interpret this as "filling up" of a basin with sediments. Deep water peats gradually build up. As the hydroperiod shortens, calcareous periphyton begin depositing calcitic mud layers.

Group D. Located in the western margin of the upper slough, Group D consists of a peat layer sandwiched between two calcitic layers. Gleason *et al.* (1984) interpreted this to represent an historical shift in hydroperiod that allowed peat to build up in a relatively wetter area. A subsequent drop in water level forced the return of a calcite-producing environment.

Group E. Located along the upper fringe zone between Taylor Slough and Florida Bay, Group E represents a transitional environment reflecting the oscillations of Holocene sea level. The alternating layers of red mangrove peat and calcitic mud indicate that neither marine nor freshwater conditions have dominated during recent time.

Group F. Located along the southern tip of the slough, Group F consists of red mangrove peat overlying a layer of calcitic mud. This arrangement supports the theory of a general transgression of the sea over south and southwestern Florida (Scholl *et al.*,1967).

Soil Classifications. The three basic soil types in the Everglades are marl, peat, and rockland soils. The ENP area contains a great variety soil categories generally falling into these three basic soil types. Table 41 lists the nine soil series expected to be found in the ENP Planning Area (SCS, 1958) along with a description of the parent material of each soil.

Table 41. Soil Series and Parent Materials of Everglades Soils.

Series	Parent Material
MARLS	
Perrine	Unconsolidated finely divided highly calcareous sediments, 6 to 60 inches (15 to 130 centimeters) deep over limestone; mainly of fresh-water origin.
Flamingo	Unconsolidated very finely divided highly calcareous marine sediments 60 to 120 inches (130 to 300 centimeters) deep over limestone; mainly formed in brackish or salt water.
Ochopee	Unconsolidated finely divided calcareous sediments (high content of fine sand); 4 to 12 inches (10 to 30 centimeters) over limestone; mainly of freshwater origin
Hialeah	Unconsolidated layers of finely divided calcareous sediments, organic remains, and fine sand; or organic remains over calcareous sediments and fine sand over soft limestone.
PEATS	
Everglades	Remains of sawgrass, lily, sedge, arrowhead, sawgrass over limestone, or shallow layer of fine sand or marl over limestone.
Loxahatchee	Remains of bladderwort, lily, sedge, arrowhead, sawgrass over limestone, or shallow layer of sand or marl over limestone.
Gandy	Remains of white bay, myrtle, rubber trees, fern,sawgrass over limestone, or shallow layer of sand or marl over limestone.
ROCKLAND	
Rockdale	Small pockets of fine sand or fine sandy loam in soft limestone.
Rockland*	Consists mostly of limestone and shallow solution holes filled with fine sand.

* Source; Description from University of Florida, Agriculture Experiment Station, 1965. All other descriptions from SCS 1946.

Marl. Marl soils vary in texture according to the particle size of their main constituent, calcium carbonate, and the amount of clay or other material mixed in (SCS, 1958). Most of the marl soils that cover extensive areas of the Everglades are of recent age, while some of the subsoil marl is Pleistocene age or older. Some of the recent soils, including marls and peats, developed over bare rock. Fine sediments washed in from the sea and deposited on the shore, as in the formation of Flamingo marl. Marl, such as Perrine, developed in fresh water from sediments washed over calcium carbonate rock. The solution and redeposition of calcareous materials, often contributed by calcareous algae, contributed to this process (Davis, 1943a,b).

Flamingo and Perrine marls may be mixed with various quantities of organic materials or sands forming marly mucks or sandy marls. Similar to Perrine marl, Ochopee is of fresh water origin but differs from other marl by a high content of fine sands. Hialeah mucky marl occurs near the eastern border of the Everglades Basin and has thin interstratified layers of marl and peat or muck.

Rockland. Much of south Florida was not covered by the Pamlico Sea of the Pleistocene Epoch, resulting in large areas of exposed rock without soil material. Most of the deep peat soils of the Everglades developed over the last few thousand years on this bare rock surface.

In large areas where the rock has not been covered with soil, collection of organics in pits and pockets of the limestone allow plant growth over most of the "rocklands", such as the Rockdale and Rockland soil groups. Areas where soil remains very thin with little vegetation cover are very sensitive to fires. Often fires reduce the shallow soil to ash and set back plant succession, thereby limiting the development of vegetation communities in the rockland.

Peat. The basin formed by the eastern rim of the Miami oolite coastal ridge increases slightly in elevation from the coast north toward Lake Okeechobee (Davis, 1946). This topographic condition favored accumulation of peat in the Everglades. Rainwater and overflow from the lake accumulated in the basin. Slow sheet flow and ponding occurred over the nearly impervious rock floor. Extensive peat and muck deposits were formed from the buildup of marsh, swamp, and aquatic vegetation and fluctuating water conditions. The type of peat formed depended upon the kind of organic and plant material, the thickness of the peat mantle, and the character of underlying materials. The main plant materials in the Everglades contributing to peat formation include: sawgrass, water lilies and emergent species, and leaves and stems of woody plants.

Different types of peat are classified by the origin of the plant material forming the deposit. Everglades peat was formed through decomposition of sawgrass, water lily, sedge, and myrtle. The other peat mucks (Everglades, Loxahatchee, and Gandy) were formed from other plant species listed in **Table 42**. Organic soils developed from the growth and decomposition of marsh and swamp vegetation. Nearly half of the peat in the United States occurs in Florida and half of the estimated original supply occurred in the Everglades (Davis, 1946).

Subsidence of the peat soils has occurred through loss of water with the construction of drainage canals since the early 1900's (Davis, 1946; Stephens, 1974). Many peat and muck areas have been burned, oxidized, subsided or washed off, because of altered water tables, removal of original vegetation, and altered drainage conditions. Instead of continued formation of the soils, soils have been depleted exposing rock, sand, or marl substrate.

Because of the direct relationship between topography and surface rock, vegetation types often form in relation to the physiographic features of rockland and thin soil areas. There is a strong correlation between topography, soil, and rock strata.

Soil Surveys of the Everglades Region. Two soils maps of Dade County have been produced. The Soil Conservation Service generated a set of 12 soils maps in 1958 (SCS, 1958). The soils were divided into 6 soil groups and 6 miscellaneous land types. There are 15 soil series divided into 37 soil types or phases. The University of Florida Agricultural Experiment Station in cooperation with the Soil Conservation Service produced a report on Soil Associations of Dade County, Florida (Leighty *et al.* 1965). This document included one soils map and a table of the soil series grouped by associations. Eight soil associations or groups were delineated including 18 soil series. A comparison of the soil classification from 1958 compared to 1965 in **Table 42**, shows that the 1965 survey contains more soil phases of each soil

Table 42. Soil Types of the Everglades

1958 Classifications	1965 Classifications
1. Moderately Well Drained Shallow Soils	Group 4 - Well Drained Rocky Soils
Rockdale fine sand, level phase - limestone complex	Rockdale fine sand limestone complex
Rockdale fine sand, undulating phase - limestone complex	
Rockdale fine sandy loam, loam - limestone complex	Rockdale fine sandy level phase - limestone complex
Rockdale fine sandy loam, undulating phase - limestone complex	
2. Poorly To Very Poorly Drained, Moderately Deep Marls	Group 5 - Poorly or very poorly drained marls
Flamingo marl	Flamingo
Hialeah mucky marl	Hialeah
Perrine marl	Perrine
Perrine marl, peat substratum phase	
Perrine marl, shallow phase	
Perrine marl, shallow, peat substratum phase	
Perrine marl, tidal	
Perrine marl, very shallow phase	
3. Poorly to Very Poorly Drained, Shallow Marls	Group 5 - Poorly or very poorly drained marls
Ochopee fine sandy marl,shallow phase	Ochopee Perrine - shallow and very shallow
4. Very Poorly Drained Organic Soils,Derived from Remains of Sawgrass	Group 6 - Very poorly drained peats
Everglades peat	Everglades
Everglades peat, over shallow marl	
Everglades peat, shallow phase	
Everglades peat, shallow phase over deep sand	
Everglades peat, shallow phase over shallow marl	
Everglades peat, shallow phase over shallow sand	
5. Very Poorly Drained Organic Soils,Derived from Remains of Woody and Succulent Aquatic plants	Group 6 - Very Poorly drained peats
Gandy peat	Gandy
Gandy peat shallow phase	
Loxahatchee peat	Loxahatchee
Loxahatchee peat, deep phase	
Loxahatchee peat, over shallow marl	
Loxahatchee peat, shallow phase	
Loxahatchee peat, shallow phase over shallow marl	
Loxahatchee peat, shallow phase over shallow sand	
6. Somewhat Poorly to Poorly Drained Rockland	
Rockland	
7. Miscellaneous Land Units	Group 7 - Miscellaneous land types
Coastal Beach	Coastal Beach
Cypress swamp	Cypress swamp
Made land	Made land
Mangrove swamp	Mangrove swamp
Mines, pits, and dumps	Mines, pits, and dumps
	Rockland

Sources:Soil Conservation Service Soil Survey of Dade County (1958) and Leighty *et al.*, 1965 type. Rockland was classified in 1958 as miscellaneous land type - not enough soil material to be classified as a true soil. In the 1965 survey, the Rockland series was reclassified as a true soil.

The latest Dade County soil survey has been completed and is expected to be printed and available to the public in 1990, but does not provide coverage of the ENP SWIM planning area.

Topography. Literature regarding topography within the planning area is not extensive. Johnson (1958) provided a brief description of surface elevations of the mainland area of ENP primarily based on data collected in the 1940s by the Soil Conservation Service. Elevations in the park ranged from about 8 feet (2 meters) above mean sea level near Tamiami Trail to mean sea level at Florida Bay. A general topographic map of the ENP was presented, but Johnson (1958) noted that the contours presented were not exact. He advised that more accurate topographic information was needed prior to any planning of water management operations.

On behalf of the South Florida Research Center (SFRC) of the National Park Service (NPS), surveys of surface elevations within major portions of the planning area were recently (ca. 1987) completed (Beedeman, personal communication). Survey transects were run westward from L-31N, with surface elevations being recorded at 400-foot (120-meter) intervals. Transects were started roughly a kilometer (0.6 mile) south of Tamiami Trail and repeated at 2 kilometer (1.2 mile) intervals. These surveys primarily provided surface elevation data for the East Everglades and Northeast Shark River Slough. Coverage of the central and southern portions of Taylor Slough and the Eastern Panhandle of the ENP was less detailed in part because survey cuts were not allowed within the park. For the same reason, limited information is available for most of the C-111 Basin.

The SFRC is working with the University of Florida and NASA in developing detailed topographic mapping of the ENP and adjacent areas based on the survey data described above (Discussion November, 1989 with Robert Johnson, SFRC-ENP). The University of Florida has prepared a contour map using these data and the SFRC has incorporated this map into its Geographic Information System (GIS). Additionally, the elevation data were provided to NASA for analysis in association with NASA's satellite imagery of the planning area. A second topographic map, thus, has been prepared which SFRC will compare with that produced by the University of Florida's contouring program. The topographic data set stored in the SFRC GIS has been requested; when received, it will be incorporated into the District's GIS database.

5. Hydrology and Hydrologic Relationships

Groundwater Resources. The hydrogeology of south Florida is extremely diverse. It includes unconfined, semiconfined and confined aquifers Three aquifer systems are identified in the Everglades SWIM area, these are the Surficial Aquifer system, the Intermediate (or Hawthorn) Aquifer system, and Floridan Aquifer system (**Table 43**). The Surficial Aquifer is the only source of potable water within the ENP SWIM Planning Area. The Intermediate Aquifer system contains a few thin layers of moderately permeable limestones which can yield small quantities of brackish water. The Floridan Aquifer is a regionally extensive, deep aquifer that contains non-potable water throughout South Florida.

Table 43. Generalized Stratigraphic Relationships in the Everglades Planning

SERIES	FORMATION	LITHOLOGY	AQUIFER SYSTEMS	WATER BEA
HOLOCENE	TERRACE DEPOSITS	FINE TO MEDIUM SUBANGULAR QUARTZ SANDS WITH MINOR AMOUNT OF SILT AND CLAY	SURFICIAL AQUIFER SYSTEM	BISCAYNE AQUIFER P SOUTHEAST FLORIDA SHALLOW AQUIFER T HIGHLY PERMEABLE I LIMESTONES AND IN S
PLEISTOCENE	MIAMI OOLITE	MODERATELY INDURATED,SLIGHTLY SANDY OOLITICLIMESTONE		
	KEY LARGO LIMESTONE	MODERATELY INDURATED, HIGHLY FOSSILIFEROUS CORALLINE LIMESTONE		OTHER WATER TABLE MODERATE PERMEAB SANDS. UNIT IS SOME UNDERLYING AQUIFE
	ANASTASIA FORMATION	SANDY LIMESTONE, SANDSTONE, SAND AND SHELL TYPICALLY OCCURRING AS COQUINA		
	FT THOMPSON FORMATION	FRESHWATER AND MARINE SHELL BEDS WITH INTER-BEDDED LIMESTONE		
PLIOCENE	CALOOSAHATCHEE FORMATION	POORLY CONSOLIDATED SANDY SHELL BEDS WITH INTER BEDDED LIMESTONE		
	TAMIAMI FORMATION	MODERATELY INDURATED, SANDY AND SLIGHTLYPHOSPHATIC LIMESTONE		
MIOCENE	HAWTHORN FORMATION	VERY HETEROGENEOUS MIXTURE OF SANDY PHOSPHATIC CLAYS AND DOLO-SILTS CHARACTERISTICALLY NTERBEDDED WITH PHOSPHATIC SANDS, DOLOMITES, AND LIMESTONES.	HAWTHORN AQUIFER SYSTEM	THE HAWTHORN FOR CONFINING BED FOR T SYSTEM OVER MOST C HOWEVER IN SOUTHW ARTESIAN AQUIFERS (HAWTHORN) YIELD M QUANTITIES OF WATE
	TAMPA FORMATION	SANDY AND PHOSPHATIC FOSSILIFEROUS LIMESTONE	FLORIDAN AQUIFER SYSTEM	OVERALL VERY HIGH DEVELOPED MOLDIC, SECONDARY SOLUTIO VERY HIGH PERMEABI FORMATION CONTAC AND LOWER MIOCEN AND LIMESTONE BED ZONES IN THE UPPER TO INTERBEDDED AN
OLIGOCENE	SUWANEE FORMATION	MEDIUM GRAINED (CALCARENITIC) LIMESTONE. SOMETIMES SANDY		
EOCENE	CRYSTAL RIVER FORMATION	THE OCALA GROUP CONTAINS PRINCIPALLY BIOGENIC AND MICRITIC COQUINOID LIME-STONES LOWER INTERVAL IN CALCARENITIC		
	WILLISTON FORMATION			
	AVON PARK FORMATION	FOSSILIFEROUS DOLOMITES AND HIGHLY RECRYSTALLIZED BIOGENIC LIMESTONES		
	LAKE CITY LIMESTONE	HIGHLY RECRYSTALLIZED DOLOMITES WITH VARYING AMOUNTS OF GYPSUM	BOULDER ZONE	ZONES OF HIGH TRAN ZONES) OCCUR WITHI LAKE CITY LIMESTON VERY HIGH LATERAL HORIZONTAL CAVITY
	OLDSMAR LIMESTONE	CHALKY AND FINELY FRAGMENTAL FOSSILIFEROUS LIMESTONE		
PALEOCENE	CEDAR KEYS LIMESTONE	HIGHLY RECRYSTALLIZED DOLOMITE AND EVAPORITES (GYPSUM AND ANHYDRITE)		

Source: Kreitman and Wedderburn, 1984

Surficial Aquifer System. Jarosewich and Wagner (1985), in a study of the geologic structure of the Surficial Aquifer system underlying ENP, found considerable heterogeneity in the lithologies but suggested two distinct zones: an upper zone of permeable limestones and clastics, and a more heterogeneous lower zone of relatively impermeable fine grained sands and silty sands interbedded with permeable sands, limestones, and shelly marls. The permeable upper zone and the permeable beds of the lower zone were considered to be hydraulically connected; therefore, the two zones were considered as a single surficial aquifer system. Presence of a regionally continuous "green clay bed" of the lower Tamiami Formation is considered the base of the aquifer system. Gleason *et al.* (1984) described the surficial aquifer system as a series of interstratified, highly permeable, and relatively impermeable layers extending from the surface down to a regionally continuous basal zone.

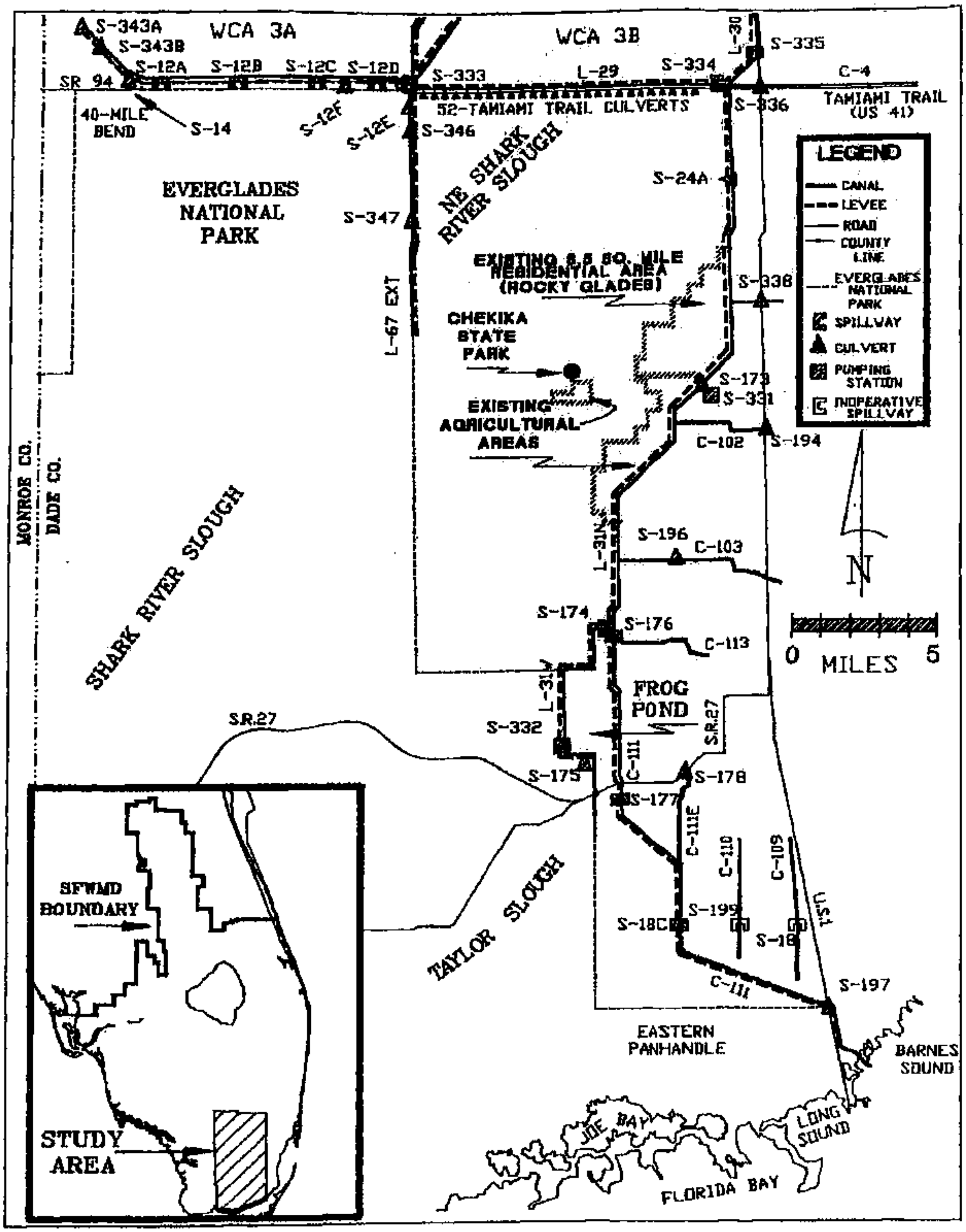
Differences in the permeabilities of the sands, limestones, marls, and silts that compose the aquifer system influence the direction and rate of ground water movement. This movement is generally slow from recharge zones where water levels are high toward coastal areas where water levels are low, and where some inland migration of seawater occurs during extended drought periods. The water table rises above the land surface over large areas in the interior because of the combined influence of low land elevation, lack of surface relief, and a seasonally plentiful rainfall. These surface waters may then flow overland along seaward gradients, but enroute also serve as a source of recharge for the surficial aquifer system. Thus, the surface and ground water systems are interrelated.

Current Drainage Basins. The ENP SWIM Planning Area includes two recognized drainage basins, Shark River Slough and Taylor Slough, located within the ENP, Northeast Shark River Slough (NESRS) located within the East Everglades Area (EEA), and the C-111 canal basin **(Figure 42)**. The current ENP basin as described by Cooper (1990, in press) includes all of the ENP, the EEA, and a portion of the South Unit of the East Everglades Wildlife Management Area (EEWMA). The EEA is bounded by L-29 on the north, L-31N on the east, and ENP on the west. The portion of the EEWMA within the ENP basin lies in south-central Dade County bounded by ENP and C-111. With the exception of the EEA/C-111 Basin, a majority of the study area is undeveloped and in public ownership. There is private development in the EEA, that is limited to an 8.5 square-mile residential area near L-31N and agriculture along the western boundary of the L-31 N levee. The EEA/C-111 Basin and headwaters of Taylor Slough are described in detail in another section of this report

Shark River Slough. Water movement in Shark River Slough depends on the timing, duration, and magnitude of flood and drought conditions. Under high-flow conditions, the velocity of sheet flow may reach 1,400 to 1,600 feet per day or about 50 miles per year. During drought, velocities may drop to zero as the water table falls below ground level (Schomer and Drew, 1982). Constantly high losses due to evapotranspiration affect sheet flow. Recent isotopic data suggests that groundwater underlying Everglades National Park is derived primarily from recent surface waters, and is heavily affected by recent rainfall recharge, while waters under Alligator Alley in Water Conservation Area 3 is much older and less directly affected by rainfall (Swart 1989, unpublished data).

Flow velocities are typically very low in the Everglades, ranging from 0 to 1 centimeter per second because of the small hydraulic gradients and resistance offered by the vegetation (Rosendahl and Rose, 1982). Water appears to move down the

Figure 42. Drainage Basins and Water Management Features of the East Everglades in the Vicinity of Everglades National Park.



sloughs in a series of sheet flow pulses (Schomer and Drew, 1982), each from a different runoff year. Seasonal pulses from Tamiami Canal are augmented by local rainfall and diminished by evapotranspiration. The pulse may travel as little as 5 to 6 miles per year or as much as 20 miles depending on the specific conditions. As each subsequent year's pulse begins, the remainder of the previous year's pulse becomes replenished by rainfall and upstream flow pushing the flow even farther down the slough, eventually into the estuarine zone.

Water Delivery and Flood Control System. Inflows to the current ENP basin include: local rainfall, surface water flow from WCA-3A to Shark River Slough through the S-12 structures and S-333, surface flow from L-31N Canal to Taylor Slough through S-332 and S-175, surface flow from C-111 to the eastern panhandle of the ENP, and the South Unit of the southwestern C-111 basin through gaps in the south berm of C-111 between S-18C and S-197 (refer to **Figure 42**). Additionally, flow into NESRS occurs through culverts under Tamiami Trail.

Pre-drainage surface water deliveries. The Everglades were not gauged sufficiently prior to major drainage system development to accurately determine pre-drainage flows to Shark River Slough. Approximate water budgets were constructed by the Central and Southern Florida Flood Control District (1950) and by Langbein (in Parker *et al.* 1955), both of which concluded that average annual predrainage inflow to Shark River Slough was in excess of 2 million acre-feet. The USCOE (Appendix B of Part I, Supplement 33 - General Design Memorandum for Conservatuioion Area No. 3 -- June, 1960) estimated that historic water deliveries to Everglades National Park, across the Taminami Canal from L-30 to Monroe Station, during averge rainfall years (57 inches) was about 1,250,000 acre-feet.

The Central and Southern Florida (C&SF) Project. The conveyance canals and control structures within Dade County are part of the C&SF Project constructed by the USCOE for flood protection, water supply and other allied purposes. The first phase of the project was authorized by the Flood Control Act of 1948. This first phase included most of the existing water control works in the Everglades Agricultural Area (EAA) south of Lake Okeechobee along with the early flood control and drainage canals in the developed areas of the lower east coast. The remaining works as well as other modifications were authorized by the Flood Control Acts of 1954, 1962 and 1968.

The first overall plan for flood protection and water control for southern Dade County was presented in the Survey Review Report on the Central and Southern Florida Project, South Dade County (USCOE, 1961). The L-31W Canal system was not included as part of this plan. The remaining major flood control and water supply facilities for southern Dade County were addressed in the General Design Memorandum (GDM), South Dade County (USCOE, 1963). The L-31W Canal and control structures S-174 and S-175 were added to the project as part of the memorandum following recommendations by the NPS and the U.S. Fish and Wildlife Service.

The first major canal constructed in Dade County was the southern end of the Miami Canal, which was built in 1912 to drain the northern Everglades basin to the Atlantic coast. In 1951, construction began on the L-30 and the northern part of the L-31N canal and levee systems. These were built as part of the eastern levee system protecting the populated east coast urban area from the Everglades during times of flooding. In 1961, construction began on the L-29 Canal and levee system which largely completed the closure of WCA-3 along the northern boundary of ENP. At this time, there was no connection between the L-30 and L-31N canals so the canal systems south of the Water Conservation Areas could be used for flood control but not water supply.

By 1965, the C-1, C-2, C-100, C-102, C-103, and C-111 had been constructed and control structures were added to all new and existing canals to reduce salt water intrusion, and to retard overdrainage of ground water. In 1966, construction began on the remainder of the L-31N Canal and structures S-173, S-176, and S-177 were added to control flows southward into the C-111 Canal. At the same time several of the earlier canals (C-1, C-102, and C-103) were extended westward to the L-31N Canal to improve flood protection and allow for water supply to these basins. Construction of the L-31W Canal and structures S-174 and S-175 began in 1968 and was completed in early 1970. At this time the system still lacked sufficient control structures to move surplus water from WCA-3A to the lower east coast.

South Dade Conveyance System. The need for more fresh water in Taylor Slough and the downstream areas of Florida Bay prompted Congress to authorize the construction of the South Dade Conveyance System (SDCS) as part of the Flood Control Act of 1968. This system of canals, control structures, and pumping stations (**Figure 43**) was added to the Project for the purposes of conveying additional water supplies for the ENP and for agricultural and urban development along the lower east coast. The system was primarily designed to provide 55,000 acre-feet per year of supplemental water to the eastern portion of the ENP to meet the congressionally mandated minimum delivery schedule.

Project Structures and Features. There are ten Project structures controlling flows within the ENP study area: S-12A, S-12B, S-12C, S-12D, S-18C, S-175, S-197, S-332, S-333, and S-334. There are two structures controlling flow within the ENP basin; S-346 and S-347. There are two other Project structures, S-12E and S-14, that connect the ENP basin to the L-29 Canal and to WCA-3A, respectively. These structures are not currently operated (Cooper 1990, in press).

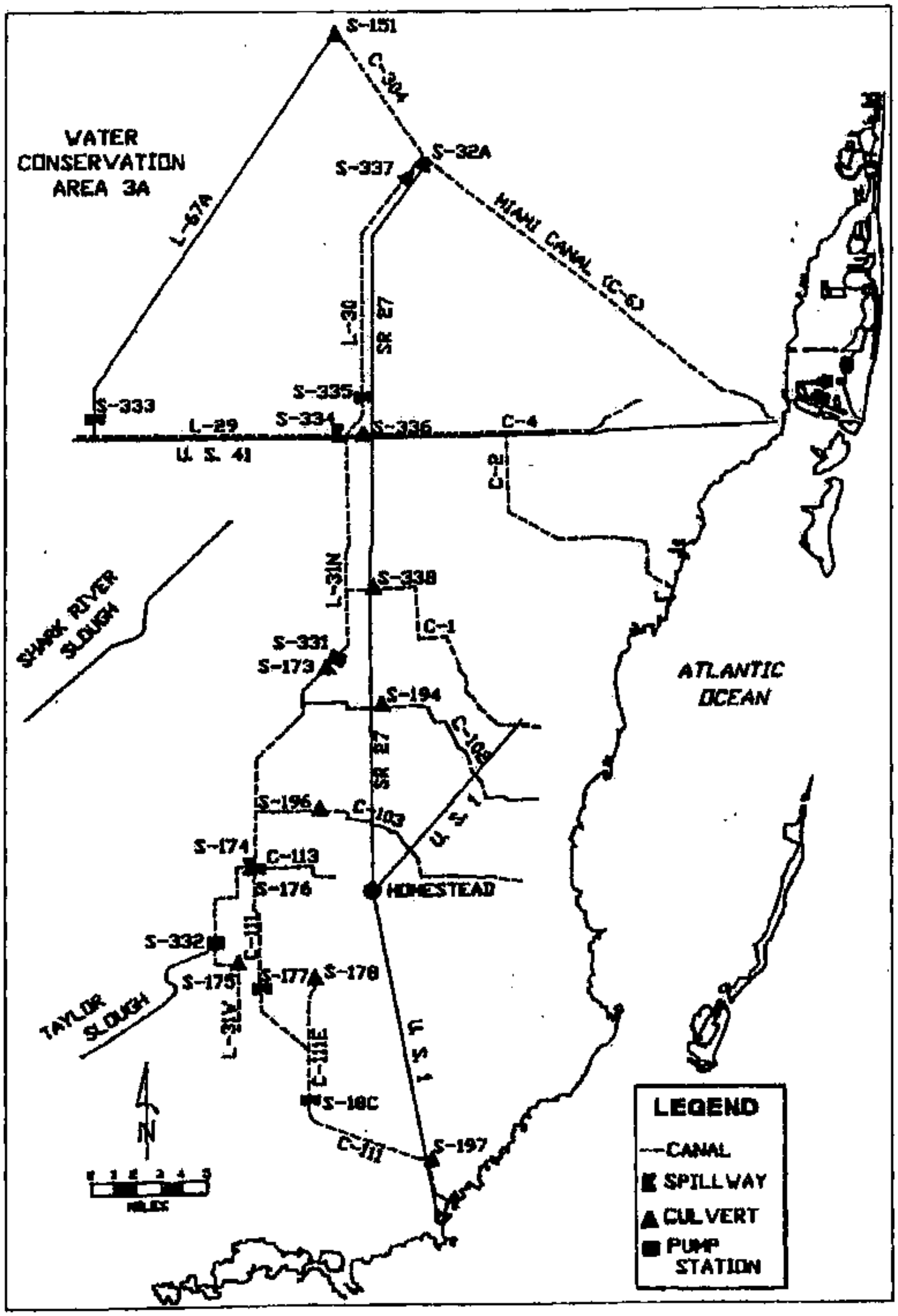
The first connection between WCA-3A and the south Dade canals occurred in 1978 with the completion of structures S-333 and S-334 in the L-29 Canal. These structures were installed to provide additional dry season water deliveries to L-31N. Another purpose of the SDCS was to supply recharge water to the Alexander Orr and the Florida City wellfields.

Project works are largely peripheral to the ENP basin and have as their primary function providing a supply of water to the basin. The L-67 Extended canal is the only Project work within the basin. The L-67 Extended Canal (**Figure 43**) serves as a "get away channel" for the discharges from the S-12 structures (Cooper 1990, in press). The channel allows water to move away from the outlet structure so that more water can move from WCA-3A to ENP. It was built as a water supply feature so that water could be put into ENP even when WCA-3A was dry.

Recent Water Delivery Schedules. Most of the surface flow entering ENP occurs through the Central and South Florida Project. Project works are largely located on the periphery of the Park. Their primary function is to supply water to the basin and to pass floodwater flows from adjacent basins into the ENP.

Water control works that were constructed immediately adjacent to Shark River Slough, Taylor Slough, the East Everglades and the panhandle of the ENP allowed water managers to regulate flow across park boundaries. Several water

Figure 43. The South Dade Conveyance System.



delivery schemes were implemented from 1962 to 1982 to meet delivery goals for the ENP. The principle such scheme was the Minimum Delivery Schedule. **Table 44** provides a summary of water delivery schedules to Shark River Slough for the period from 1962 to 1982.

Table 44. Summary of Water Delivery Schedules to Shark River Slough.

Schedule (Dates in Effect)	*Summary*
1. Conservation Area 3A Stage (Dec. 1962 - Mar. 1965)	*Park only to get excess water once Conservation Areas filled.*
2. Conservation Area 3A Stage (Mar. 1965 - Mar. 1966)	*All excess to park through S-12s.*
	3 stage zones dictated 3 different monthly delivery schedules.
	P-33 as override.
3. Lake Okeechobee Stage (Mar. 1966 - Feb. 1970)	*13.5-15.5 * feet - 1000 cfs through S-12s.*
	12.5-13.5 feet - 140 to 150 cfs through S-12s.
	Below 12.5 feet - no delivery.
4. Lake Okeechobee Stage (Feb. 1970 - Sept. 1970)	*Above 12.5 feet - 260,000 acre-feet through S-12s.*
	Below 12.5 feet - reduced % of schedule.
	P-33 as override.
5. Congressionally mandated minimum delivery schedule (1970-1982)	*260,000 acre-feet minimum delivery through S-12s.*
	Provisions for reduction to share adversity in drought.

* = National Geodetic Vertical Datum (NGVD). (Modified from: Wagner and Rosendahl, 1987)

Minimum Delivery Schedule. Two studies in the 1960s allowed development of interim Shark River Slough water delivery schedules. A minimum monthly Shark River Slough delivery schedule was adopted by Congress in 1970, as Public Law (PL) 91-282. Dunn (1961) analyzed Shark River Slough discharge records for a 6-year period (1947 to 1952), and recommended adoption of the median annual flow (273,000 acre-feet) as the minimum annual delivery requirement for the slough. Based on an evaluation of data for the period October 1953 to September 1962 (stage-duration curves at central Shark River Slough recorder P-33 and a stage-discharge relationship between P-33 and flow to Shark River Slough), Hartwell, *et al.* (1963) recommended an annual discharge requirement of 243,580 acre-feet. The NPS roughly averaged these two values to arrive at the 260,000 acre-feet minimum water delivery requirement for Shark River Slough that was eventually incorporated into PL 91-282 (Wagner and Rosendahl, 1987).

PL 91-282 contained a minimum delivery schedule for Taylor Slough based on the work of Dunn (1961). The estimate of locally derived flow in Dunn's work was based on less than a years flow records at U. S. Geological Survey (Miami) flow section "Taylor Slough near Homestead" (Wagner and Rosendahl, 1987). This method estimated the spillover from Shark River Slough and added it to flow for an annual amount of 55,000 acre-feet of water. The median discharge value (38,000 acre-feet) was recommended as the minimum requirement and ultimately, a value of 37,000 acre-feet appeared in PL 91-282 as the minimum annual requirement for Taylor Slough (Wagner and Rosendahl, 1987). The minimum delivery schedule for the ENP's eastern panhandle designated in PL 91-282 was 18,000 acre-feet. The PL

91-282 schedule was the first to both guarantee minimum monthly water rights for the ENP and provide a mechanism for sharing adversity in times of drought.

The interim delivery schedules of the late 1960s, and PL 91-282, did nothing to relieve the drastic alteration of water distribution to Shark River Slough that accompanied completion of WCA-3A. Prior to the completion of L-29 and the S-12 structures in 1962, 34 percent of the total annual flow to Shark River Slough was through L-67A to the 40-Mile Bend flow section, with 66 percent through the eastern flow section (L-30 to L-67A) (Wagner and Rosendahl, 1987). L-67 extended was completed in 1967 at the request of several interests, including the park, to deliver more water to the heart of Shark Slough. Wagner and Rosendahl (1987) describe a reversal in spatial distribution, with 92 percent of annual flow going to the western half of Shark Slough after delivery schedules were instituted and L-67 extended completed.

From 1971 to 1982, 11 consecutive years of below average, basin wide rainfall occurred, but the water management system delivered substantially more water to Shark River Slough than in comparably dry periods before the 1970 delivery schedule was adopted. Delivery problems to the park included unnatural timing of delivery, with unnatural volumes of water being delivered at times when the southern parts of the system should have been drying and dry periods when the area should have been filling with water. Timing of water deliveries caused failure of alligator nesting, bird rookery abandonment and disruption of natural aquatic communities (NPS-SFRC, 1989). In 1984 a test schedule of a water delivery model was implemented. This water delivery model, the Rainfall Plan, was based on upstream water events and rainfall to approximate a more normal hydroperiod and hydro-pattern (MacVicar, 1985; Neidrauer and Cooper, 1989).

Water supply to Taylor Slough and to the panhandle of the ENP is required by law to be at least 55,000 acre-feet per year (37,000 acre-feet to Taylor Slough and 18,000 acre-feet to the panhandle). Water table elevations in the eastern-most portions of the East Everglades Area are to some degree controlled by water levels in L-31N (Neidrauer and Cooper, 1989). Since the completion of the South Dade Conveyance System and the increase in development west of L-31N more water has been moved down this canal (Neidrauer and Cooper, 1989). In order to maintain a water table elevation in the East Everglades and in the Frog Pond Area acceptable to the residents and growers in those areas, water must be continually discharged from L-31N Canal. This is accomplished by pumping at S-332 and discharge through S-175 and S-18C. Currently this water is moved to the south and discharged through the gaps between S-18C and S-197 where it then flows overland into northeast Florida Bay, primarily at Long Sound. The park has requested that more water be distributed down Taylor Slough to re-wet this part of the system and to add more water to Florida Bay in a more natural manner.

<u>The Seven Point Plan.</u> By 1983, it was evident that the minimum delivery schedule was altering the natural plant communities within ENP. At that time ENP requested that the District and the USCOE institute seven protective measures. These seven measures have subsequently been termed the Seven Point Plan. The concerns over the distribution and timing of water flow were expressed in the Park's Seven Point Plan which is described in **Table 45**. In 1983, at the same time the Seven Point Plan was proposed, the USCOE was considering changes in the water delivery system to the ENP.

Table 45. The Seven Point Plan.

1. **Fill in L-28 Canal and Remove Levee Segments.** L-28 Canal is over-draining the eastern Big Cypress during the dry season, and the levee prevents high water from moving into Big Cypress as it traditionally did. Removal of the levee will provide some flood relief to ENP and restore high-water flow through several historical drainage channels.
2. **Fill in L-67 Extended Canal and Remove Levee.** Water deliveries to the ENP through this canal at times cause abnormal flooding of the ENP during the dry season, and the levee prevents the historical hydrological connection with deep-water areas in NESRS.
3. **Restore WCA-3B to the Everglades System.** Divert as much flow as is environmentally acceptable into WCA-3B.
4. **Distribute Water Deliveries Along the Tamiami Canal.** Distribute water deliveries from WCA-3A along the full length of the Tamiami Canal from L-28 to L-30. The prevention of flow to NESRS from WCA-3A has stressed aquatic communities within ENP.
5. **Establish a Water Quality Monitoring Program.** Establish a water quality monitoring program to provide methods to detect degradation of delivery waters to ENP.
6. **Defer Implementation of New Drainage Districts.** Defer implementation of new drainage districts such as proposed for the East Everglades, until the full impact of any potential flood discharges to ENP are thoroughly addressed and all possible mitigation of impacts to the ENP is considered.
7. **Field Test a New Water Delivery System to ENP.** The present water delivery system to the Park is not working. The new delivery schedule should be based upon a reference station in the Big Cypress that predicts water deliveries to Shark River Slough based upon current rainfall and normal runoff, rather than upon upstream water management. Any quantities above that predicted will be considered flood discharges and all efforts should be made to divert these excess flows.

Rainfall Delivery Plan. In 1983, the U.S. Congress passed legislation (PL 98-181) which allowed the District and the NPS to temporarily set aside the Minimum Delivery Schedule of 1970. This allowed implementation of a series of experiments to test alternative management plans for water delivery to Shark River Slough which were more related to rainfall patterns (i.e., the Rainfall Plan).

In 1985 the District, in cooperation with ENP and the Jacksonville Office of the USCOE, developed the Rainfall Plan using the following objectives:

* To base the amount and timing of water deliveries to Shark River Slough on recent weather conditions (rainfall and evapotranspiration) upstream of the slough in WCA-3A
* To moderate the sudden changes in flow that occurred under the Minimum Delivery Schedule
* To redistribute flow across the entire width of the slough, restoring flow to the eastern flow section and NESRS.

Amount and Timing of Flow. One of the most important characteristics of surface water flow driven by natural upstream rainfall is the inherent variability in the amount and timing of flow. Under the Minimum Delivery Schedule, water deliveries were made according to a set schedule without regard to upstream meteorological conditions. The amount and timing of surface water flow to Shark River Slough were not variable under this plan except under flood conditions.

The model that was used to design the Rainfall Plan was based on a statistical correlation between historical upstream weather conditions in WCA-3A and historical discharge to the slough (Neidrauer and Cooper, 1989). The correlation is based on the first complete period of the hydrologic record available. The model relates the current week's flow rate to the previous week's rate of rainfall and evaporation in each of the previous ten weeks (Neidrauer and Cooper, 1989). Under this plan, discharges are calculated on a week-to-week basis. As much as possible, 45 percent of the total calculated discharge is released to ENP on the west side of L-67 Extended through the S-12 structures and the remaining 55 percent is discharged to NESRS through S-333 and the L-29 Canal. Flow passes from the L-29 Canal to the slough through culverts under U.S. Highway 41 located between L-67 Extended and S-334 (Neidrauer and Cooper, 1989).

With the current system of canals, structures and levees, the amount and timing of surface water flow to Shark River Slough cannot be based solely on historic response of the basin to rainfall. The storage capacity of the WCAs is limited, and water in excess of this storage capacity must be discharged to prevent failure of the impounding levees. If the amount of water to be discharged to Shark River Slough, as determined by the model, is not enough to keep water level in WCA-3A within its regulation schedule, then a "regulatory release" must be made in addition to the discharge calculated by the model.

Moderation of Abrupt Changes in Flow Rate. The Rainfall Plan improves the way in which regulatory releases are made. Under the Minimum Delivery Schedule, excess water in WCA-3A was released according to a regulation schedule that caused abrupt changes in the rate of water delivery. Under the Rainfall Plan, the regulation schedule for WCA-3A has been modified so that a gradual change in the flow rate of water from WCA-3A occurs as the water level in the WCAs change.

Distribution of Flow in Shark River Slough. The third objective of the Rainfall Plan is to return water flow to the entire width of Shark River Slough instead of confining flow to the western section. Achieving this objective requires restoration of surface water flow to NESRS. For the hydrologic year (June to May) prior to the construction of L-31N and L-30, the distribution of surface water flow to the eastern and western flow sections was a function of discharge. For flow up to 450,000 acre-feet per year, the percent of flow to the eastern flow section increased with increasing discharge. For flow in excess of 450,000 acre-feet per year, the percent of flow to the eastern flow section remained constant at about 60 percent. During the two-year test (described below) a split of 45 percent of the total flow to the western flow section (to ENP) and 55 percent to the eastern flow section (to NESRS) was agreed to by the District, the USCOE, and ENP (Niedrauer and Cooper, 1989).

During the test, water from WCA-3A was discharge to the western flow section through the S-12 structures, and to the eastern flow section through S-333 and the L-29 Canal (**Figure 42**). Fifty-three culverts under the Tamiami Trail connect the L-29 Canal to NESRS. Rate of discharge through these culverts is determined by the discharge at S-333 and the water level held in the L-29 Canal by S-334.

Field Tests of Alternative Delivery Plans. The District conducted 30- and 90-day tests to determine the feasibility of restoring flow to NESRS (MacVicar and VanLent, 1984; MacVicar, 1985). The purpose of these tests was to determine if sufficient volumes of water could be discharged to NESRS by the structures and canals involved, and whether these volumes of water would cause flooding to the Rocky Glades residential and agricultural areas east of NESRS and west of L-31N.

These areas are outside of the formal flood control project and are located in a wetland and therefore are subject to flooding for this reason. Periodic inundation of this former wetland results from its low ground elevations and the hydrologic regime. When these projects were proposed, there were concerns that further structural and operational changes in the water management system to benefit ENP would aggravate the flood conditions in this region.

The 30-day test was conducted during the dry season from April 19, 1984, to May 18, 1984. A total of 61,000 acre-feet of water was discharge to NESRS during the test. Results of the test showed that large volumes of water could be discharged to NESRS through S-333 and the L-29 Canal, and that for dry-season conditions, discharge of water to NESRS posed no threat of flooding to nearby residential and agricultural areas. It remained to be shown that water could be successfully delivered to NESRS during the wet season.

The 90-day test was conducted during the wet season from August 1, 1984 to November 30, 1984. During the test, 118,000 acre-feet of water were discharged to NESRS. Results showed that it was feasible to deliver water to NESRS through S-333 and the L-29 Canal during the wet season, and that these deliveries could occur without causing flooding in nearby residential and agricultural areas.

This area historically occupied by NESRS is a depression bounded on the west by a ridge that hydrologically separates this area from the eastern Rocky Glades area which contains the existing urban and agricultural development. Both tests showed that regulation of the water levels in the L-31N Canal is effective in controlling ground water levels in the Rocky Glades area. A conclusion of the second report was that flexible operational criteria are needed to prevent unnecessary removal of ground water from the area. This test situation for water deliveries based on the rainfall plan was allowed to continue based on the results derived from the 30, and 90 day tests as well as the results of the two year test of the plan. Because of the success of this test period the rainfall plan continues in effect until responsible agencies have agreed to alter the deliveries, continue the test or the USCOE finishes its GDM for NESRS. Based on the two-year test, Neidrauer and Cooper (1989) concluded the following:

1. Important aspects of the pre-development spatial and temporal patterns of surface water flow to Shark River Slough were reestablished in the Slough. These aspects were correlation of flow to rainfall, variability in amount and timing of flow, and distribution of flow across the entire slough.
2. The abrupt changes in flow experienced under the Minimum Delivery Schedule were moderated under the Rainfall Plan. Hydrographs of discharge to Shark River Slough under the Rainfall Plan exhibited a more natural response to upstream rainfall. This natural response was illustrated by a gradual rise in the hydrograph and an extended recession.
3. The regulatory component of discharge during significant periods of the test were as much as twice the rain-driven component, significantly increasing the target flow to Shark River Slough. Although this extra flow was necessary to maintain the integrity of the WCAs, it was not tied to the upstream rainfall conditions used by the statistical model to calculate the

rain-driven component of discharge. It was the result of the diversion of surface water to the south by L-31N and L-30.

4. Discharge through S-333 was limited for significant periods during the test (usually for flows greater than 1,100 cubic feet per second, cfs), because water levels in the L-29 Canal were restricted to less than 7.50 feet. Limited flow through S-333 impacted the test in two ways:
   a. The actual discharge to Shark River Slough was often less than the target discharge (84 percent of target for the periods of the test). Discharge was limited during the wet season. Dry season discharge was on target.
   b. It was not possible during periods of limited discharge through S-333 to achieve the desired distribution of flow to Shark River Slough. The percentage of the surface flow to Shark River Slough discharged to the eastern flow section decreased with total surface flow discharged, the inverse of the historic relationship between these parameters.

5. The combination of rainfall and surface water discharged to Shark River Slough during the test was not sufficient to bring water levels in the slough to levels under which the Loxahatchee peats in the slough presumably formed. Hydrographs for sites in the slough were adequate for peat formation for one site near the L-31N Canal.

6 The two-year test of the Rainfall Plan was implemented with the agreement between the District and the south Dade County Farmers.

7. The flood risk to the Rocky Glades residential and agricultural areas did not increase with the implementation of the Rainfall Plan. There is evidence to suggest that the areas had lower flood risk during the test than prior to the test.

8. Closing S-333 when the water level in the key monitoring well (G-3273) exceeded its trigger was unnecessary. Ground water levels in the Rocky Glades area under conditions of the test did not respond to discharges at S-333.

9. Regulating the water level of the L-31N Canal was effective in moderating ground water levels in the Rocky Glades area.

General Design Memorandum (GDM)-- Modified Water Deliveries to ENP. The USCOE is currently considering a GDM that would change the way water deliveries are made to ENP. Until recently, most of the water delivered to the ENP originated in WCA-3A and was passed to the ENP west of L-67 Extended through the S-12 structures. The deliveries were made according to a fixed delivery schedule and by the need to maintain WCA-3A at its regulation schedule. It has become apparent that the temporal and spatial distribution of these deliveries is having adverse effects on the natural environment in the ENP (Neidrauer and Cooper, 1989). The USCOE's GDM is being developed to respond to concerns about distribution of water to ENP.

Within this GDM, the USCOE proposes changes to the canals and structures, and proposed methods of operation of the structures that if implemented would, as nearly as possible, return the hydrology of ENP to historic conditions. The physical system would be changed to allow more water to be delivered to ENP through NESRS east of L-67 Extended. There are four major modifications being considered:

* Construction of structures in L-67A to allow water to be passed from WCA-3A to WCA-3B

* Construction of structures in L-29 to allow water to be passed from WCA-3B to NESRS
* Removal of L-67 Extended and filling of the borrow canal
* Construction of a levee around a residential area in the East Everglades west of L-31N to protect the area from surface inflow flooding.

Under the GDM, operation of new and existing structures would be changed to allow water deliveries to be more "natural" based on meteorological cycles in ENP.

6. Water Quality

Water Quality Issues. Currently, water reaching the ENP has generally been of good quality. However, the NPS has expressed concern over excessive nutrients in surface water entering ENP from the WCAs. Average nutrient concentrations in waters discharged from federally owned C&SF Project structures into ENP currently meet the water quality standards contained in a Memorandum of Agreement (MOA) jointly developed by the USCOE, NPS, ENP and SFWMD in 1979 and later revised in 1984 based upon criteria for acceptable inflow water quality developed by ENP scientists. Nutrient levels currently entering ENP should be considered excessive, based upon current knowledge, and potentially harmful to ENP's flora and fauna. Concentrations of nutrients in waters that discharge to ENP average near marsh background water quality.

The District concurs with comments by the NPS that the quality of water discharged to ENP must be maintained at non-degradation levels to protect the unique wetland resources of the park. Consequences of water quality degradation should be addressed before, rather than after, biological changes have occurred. With this proactive attitude in mind and considering the fact that current knowledge indicates that previous water quality standards were not properly developed, it is reasonable to reduce the concentration of nutrients in surface waters entering ENP from the WCA's.

NPS has also expressed the concern that potential changes in agricultural and urban land use within the East Everglades and C-111 basins may have an impact on water quality discharged to the park through the Taylor Slough and the C-111 canal (see later discussions of water quality in the C-111/East Everglades basin section of this plan). These issues will be addressed in the on-going development of Outstanding National Resource Waters (ONRW) standards proposed for ENP; but in the interim, nutrient levels in surface waters entering ENP from these areas should also be reduced..

Water Quality Criteria. Surface water quality criteria standards differ for different parts the ENP planning area, depending on jurisdictional responsibilities, standards and criteria established by the various regulatory agencies and entities. Water entering the East Everglades must conform to Dade County and Florida State Class III water quality standards. In addition, surface waters of Chekika Hammock State Park must meet state standards for Outstanding Florida Waters (OFW).

Water entering the ENP must meet both state standards for OFW and the water quality standards contained in a Memorandum of Agreement (MOA) jointly developed by the USCOE, NPS, ENP and SFWMD in 1979 (Table 46). Water quality

Table 46. Comparisons of Water Quality Criteria in the ENP SWIM Planning Area.

SURFACE WATER

	Florida[a] Class III	USCOE/ENP/SFWMD MOA Criteria
Dissolved Oxygen	5	4.5
Specific Conductance	1275[c,d]	647
pH (units)	6.0-8.5	7.6-8.0
Color (PCU)		124
Turbidity (NTU)	<29 above background	11
Total Phosphorus		0.24
Nitrate		0.7
Nitrite		0.04
Ammonia		0.24
Un-ionized Ammonia	0.02	
Organic Nitrogen		2.1
BOD	5	3
Fecal Coliform (MPN/ml)	e	
Total Coliform (MPN/ml)	f	
Alkalinity (as $CaCO_3$)	20	269
Calcium		86
Magnesium		25
Sodium		93
Chloride		143
Chlorine (Total Residual)	10	
Fluoride	10[c]	
Sulfide		
Arsenic (ug/l)	50[c]	20
Beryllium (ug/l)	1.1	
Boron (ug/l)	100	
Cadmium (ug/l)	1.2	10
Chromium (ug/l)	1,000[c]	
Copper (ug/l)	30	8
Iron (ug/l)	1,000	270
Lead (ug/l)	30	13
Mercury (ug/l)	0.2	0.5
Nickel (ug/l)	100	
Selenium (ug/l)	25	
Silver (ug/l)	0.07	
Zinc (ug/l)	30	72
Aldrin (ug/l)		0.0 [g]
Dieldrin (ug/l)		0.0 [g]
Aldrin + Dieldrin (ug/l)	0.003	
Chlordane (ug/l)	0.01	0.0 [g]
DDD (ug/l)		0.0 [g]
DDE (ug/l)		0.0 [g]
DDT (ug/l)	0.001	0.0 [g]
Diazinon (ug/l)		0.0 [g]
Demeton (ug/l)	0.1	
Endosulfan (ug/l)	0.003	
Endrin (ug/l)	0.004	0.0 [g]
Ethion (ug/l)		0.0 [g]
Guthion (ug/l)	0.01	
Heptachlor (ug/l)	0.001	0.0 [g]
Heptachlor E (ug/l)		0.0 [g]
Lindane (ug/l)	0.01	0.0 [g]
Malathion (ug/l)	0.1	0.0 [g]
Methoxychlor (ug/l)	0.03	
Methyl Parathion (ug/l)		0.0 [g]
Mirex (ug/l)	0.001	
Parathion (ug/l)	0.04	0.0 [g]
Toxaphene (ug/l)	0.005	0.0 [g]
2,4,5-T (ug/l)		0.0 [g]
2,4,5-TP (Silvex) (ug/l)		0.0 [g]
Trithion		0.0 [g]
Methyl Trithion		0.0 [g]
Pthalate Esters (ug/l)	3.0	
PCB (ug/l)	0.001	0.0 [g]
Cyanide (ug/l)	5.0	

Source: based on data Compiled by CH_2MHill
All values in milligrams per liter unless otherwise noted
a For predominantly freshwater
c General Criteria, Chapter 17-3.061, FAC
d No greater than 50 percent above background, or 1,275 umhos/cm, whichever is greater
e monthly average not to exceed 200/1000 ml; 400/100 ml for 10% of samples; 800/1000 ml for any sample
f monthly average not to exceed 1000/100 ml; 1000/100 ml for 20% of samples; 2400/100 ml for any sample
g Concentrations of pesticides in water to be 0.0. Actual concentrations to be below limits of detection.

Table 46(Cont.). Groundwater Water Quality Criteria in the ENP SWIM Planning Area.

GROUNDWATER

	Florida[b] Class G-II
pH (units)	6.5
Color (PCU)	15
Total Dissolved Solids	500
Ammonia	
Total Coliform (MPN/ml)	
Sodium	160
Chloride	250
Fluoride	2
Sulfate	250
Sulfide	
Arsenic (ug/l)	50
Barium (ug/l)	1,000
Cadmium (ug/l)	10
Chromium (ug/l)	50
Copper (ug/l)	1,000
Iron (ug/l)	300
Lead (ug/l)	50
Mercury (ug/l)	2
Selenium (ug/l)	10
Silver (ug/l)	50
Zinc (ug/l)	5,000
Endrin (ug/l)	0.2
Lindane (ug/l)	4
Methoxychlor (ug/l)	100
Toxaphene (ug/l)	5
2,4-D (ug/l)	100
2,4,5-TP (Silvex) (ug/l)	10
Total Trihalomethanes (ug/l)	100

All values in milligrams per liter unless otherwise noted
[b]Includes Primary and Secondary Drinking Water Standards (Chs 17-22.200 and 17-22.220, FAC)

standards for the ENP were developed by the NPS in the 1970s (Rosendahl and Rose, 1979). When the U.S. Congress established a minimum water delivery schedule for Everglades National Park (Public Law 91-282), Congress directed the USCOE and NPS to reach an agreement "on measures to assure that the water delivered to the Park is of sufficient purity to prevent ecological damage or deterioration of the Park's environment" (U.S. Senate, 1970). NPS was also directed by Congress (under Public Law 91-282) to report on the water quality needs of the ENP. The director of the NPS was given the right to refuse water not meeting the water quality standards addressed in the U.S. Department of Interior report, "Appraisal of Water Quality Needs and Criteria for Everglades National Park" (U.S. National Park Service, 1971).

A water quality monitoring program was developed by NPS, in cooperation with the U.S. Geological Survey (USGS), to provide the data required for water quality standards development. Water quality data were collected from 1970 to 1978 at in-park and water delivery sites. At the time of analysis, the water of selected delivery sites was determined to be of sufficient quality to be adopted as criteria against which future water quality could be compared (Rosendahl and Rose, 1979). Data from two water delivery sites, S-12C and L-67A, were used to develop standards for 36 water quality parameters. These standards were adopted in a Memorandum of Agreement (MOA) among the NPS, USCOE, and the South Florida Water Management District (District) in 1979. ENP standards have also been established for 22 different pesticides, herbicides, and PCBs (Pfeuffer, 1985).

Under the MOA, a violation is defined to have occurred if the annual average exceeds the levels established as criteria. This means that a number of measurements on a given parameter may occasionally exceed the criteria during the year without a violation occurring. This is in contrast to the Florida Class III standards which apply to instantaneous measurements. However, the intent of the MOA is to "...assure that the water delivered to the park is of sufficient purity to prevent ecological damage or deterioration of the park's envirnment".

The interagency MOA was updated in 1984. The water quality criteria agreed to under the 1984 MOA are applied to waters currently delivered to the ENP (**Table 46**). Water quality parameters to be analyzed were reduced to 24 but the number of sample locations was increased. The scope of pesticide monitoring has increased because of concerns regarding potential effects of agricultural and pest control applications.

Groundwater. All water entering the Biscayne aquifer must conform to Florida Class G-II groundwater criteria (**Table 46**). Because the Biscayne aquifer is highly permeable and vulnerable to contamination through its recharge zone, and because it is the sole source of drinking water for all municipal water systems south of Palm Beach County, the U.S. Environmental Protection Agency (EPA) has designated the Biscayne aquifer as the "sole-source aquifer." This designation provided by the Safe Drinking Water Act of 1974 (P.L. 930523), requires studies to determine that federally financed projects will not contaminate these designated sole-source aquifers.

ENP Surface Water Quality Programs and Studies. An overview of ongoing water quality programs and specific relevant short-term studies in the planning area is provided in the following section. The information provided is not intended to be comprehensive, but rather to give an outline of the major water quality efforts and the agencies involved.

USGS. Historically, the U.S. Geological Survey (USGS) has had a primary role in collection of water quality information in South Florida. Since the 1950s, agreements with several state and federal agencies have involved USGS in water quality studies in and around the ENP. Because of various needs and conditions of agreements, much of the earlier data collection was primarily non-nutrient data (i.e., specific conductance, temperature). Some of these data have been published (Goolsby *et al.* 1976; Joyner, 1973; Miller, 1975). The data were incorporated into the national USGS WATSTORE data base (Flora and Rosendahl, 1982) and were published annually in "Water Resources Data in Florida, Part 2, Water Quality Records".

In 1972, at the request of the USCOE, the USGS implemented one of many water quality monitoring programs to be initiated near the ENP. Of the 25 sites monitored in this network, 6 were relevant to the ENP Planning Area. These six stations included five monitoring stations along the Tamiami Canal and one station on L-31W upstream of S-175. By the late 1970s, this program had been discontinued.

USCOE/ SFWMD/ NPS/ ENP Memorandum of Agreement. Under the 1979 Memorandum of Agreement, a program was initiated to monitor the quality of water delivered to the ENP through water control structures at L-67A, L-31W, C-111, and the Tamiami Trail at 40 Mile Bend (part of the Big Cypress drainage basin). Sampling and analytical responsibility originally belonged to the USCOE. Water samples were collected monthly for physical parameters, nutrients, ions, and trace metals analyses, and quarterly for pesticide analyses. Sediment samples were collected semi-annually for trace metal and pesticide analyses.

The 1984 MOA continued this water quality program but reduced the number of parameters to be analyzed. Both the USCOE and the SFWMD were responsible for collecting water samples. Changes to the parameter list reflected a review of the previous 5 years of data. The limits for pesticides remained the same but biannual sediment sample collection was initiated for which pesticides, herbicides and PCBs were analyzed (Pfeuffer, 1985).

Under the current MOA, the SFWMD and USCOE are responsible for monitoring water quality at the structures along the L-67A, L-31W and C-111 Canals. The USCOE sample locations include S-333, S-332, and S-18C. The SFWMD also samples at these locations, as well as at S-12D. Additional watershed stations monitored by the District were added (Germain and Shaw, 1988). These include S-176, S-177, S-178, and two stations along the Tamiami Canal west of S-12A.

Data collected by the District is provided to ENP and USCOE (Germain and Shaw, 1988). Meetings between ENP, USCOE and the District occur, at least annually, to discuss water quality violations and the water quality parameter list, the latter which undergoes periodic revision (Germain and Shaw, 1988). For example, because water column analyses showed no detectable pesticides, analysis for pesticides in the water column was suspended for several years and only sediment samples were analyzed. Water sampling for pesticides was resumed on a quarterly basis in January 1987.

District/NPS Marsh Monitoring Program. A sampling program initiated in the fall of 1985 includes collection of monthly water quality samples at nine marsh sites within or adjacent to ENP. NPS collects the samples and the District conducts the analyses and handles database management (Scheidt *et al.* 1987). Analyses include nutrients, major ions, and trace metals. Data from this program are in unpublished form.

District Surface Water Quality Monitoring Network. The District monitors a number of watershed sites in South Florida. Those important to the ENP Planning Area include S-12A, S-12B, S-12C, S-12D, S-333, S-151, and S-9 (Germain and Shaw, 1988). These stations have been sampled biweekly since 1978 for nutrients, quarterly for major ions, and biannually for trace metals.

Short-Term Studies. Under a joint District/USGS Water Quality Monitoring Program (1976-1980), water and/or sediment samples were collected at different locations in South Florida each year (a total of 111 sites). Analyses were carried out by USGS on samples collected by District personnel. Only three sites (along the Tamiami Canal) are relevant to the study area and only sediment samples were collected (1976 only). Sediment samples were analyzed for chlorinated hydrocarbons, organophosphorus pesticides, herbicides, polychlorinated biphenyls (PCBs), and polychlorinated naphthalenes (PCNs).

In addition, the NPS monitored specific conductance and other water quality parameters more intensely (97 locations biweekly) from December 1977 to September 1979 in Shark River Slough to document seasonal and temporal changes. The purpose of this study was to attempt to correlate water quality with man-induced changes in the hydrological system (Flora and Rosendahl, 1981). USGS has sampled periodically for a variety of water quality parameters in various areas in or adjacent to the ENP. The agency sampled for common chemical constituents in Shark River estuary beginning in 1960. Concentrations of trace elements, heavy metals, and insecticides were determined in late 1966. Samples were analyzed for total nitrogen (TN) and phosphorus (TP) during the 1968-1969 study period (McPherson, 1970).

The USGS has also provided the NPS with data on natural hydrologic regimes and water quality conditions in Taylor Slough (Earle and Hartwell, 1973). Water quality records for 1960 to 1968 were analyzed for a limited group of water quality parameters (calcium, iron, nitrate, sulfate, and dissolved solids).

Surface Water Quality Data. Surface water quality data from published reports and literature are summarized in Appendix C, Tables C-16 through C-22. The data were compiled to provide an overview of available published information. There are several sources of data, primarily the District, the ENP, and DERM. Descriptions of water quality station locations have been compiled from the literature for ENP (**Table 47 and Figure 44**).

Table 47. Surface Water Quality Stations in Everglades National Park.

Station Number*	Description	Reference
S-12A	Gate Structure along US-41	Germain and Shaw, 1988
S-12B	Gate Structure along US-41	Germain and Shaw, 1988
S-12C	Gate Structure along US-41	Germain and Shaw, 1988
S-12D	Gate Structure along US-41	Germain and Shaw, 1988
P-33	Shark River Slough freshwater station	Waller, 1982a
P-34	Shark River Slough freshwater station	Waller, 1982a
P-35	Shark River Slough estuarine station	Waller, 1982a
P-36	Shark River Slough freshwater station	Waller, 1982a
P-37	Taylor Slough freshwater station	Waller, 1982a
P-38	Everglades freshwater station	Waller, 1982a
L-67A	Canal L-67A above S-333	Germain and Shaw, 1988
S-333	S-333 pump station on L-67A	Germain and Shaw, 1988
1	Taylor Slough near Homestead	Waller, 1982a
2	Taylor Slough near Royal Palm	Waller, 1982a
3	Highway 27 near Royal Palm	Earle and Hartwell, 1973
4	Cottonmouth Camp	McPherson, 1971
5	South end of L-67A extended	Waller, 1981

Source: Data Compiled by CH_2MHill

Surface water quality data from published sources are compiled in **Appendix C** as follows:

Table C-16. Phosphorus, nitrogen, and organic and inorganic carbon (TOC and TIC)
Table C-17. Alkalinity, specific conductance, and major ions
Table C-18. Metals
Table C-19. Miscellaneous water quality parameters
Table C-20. Pesticides: Chlorinated Hydrocarbons
Table C-21. Pesticides: Organophosphates and other compounds
Table C-22. Coliforms

ENP water quality criteria developed under the MOA as well as state water quality criteria are presented in **Table 46**. Comparison of ENP standards to water quality parameter averages can provide a method to determine potential problem areas of water delivery sites.

Unpublished summary review tables of water quality at the ENP inflow stations from 1984 to 1987 are included separately in **Appendix C** (SFWMD, 1989). Included in Appendix C are the following:

Table C-23. ENP 1984 Annual Averages

Figure 44. Location of Major Drainageways and Water Quality Sampling Stations in Everglades National Park.

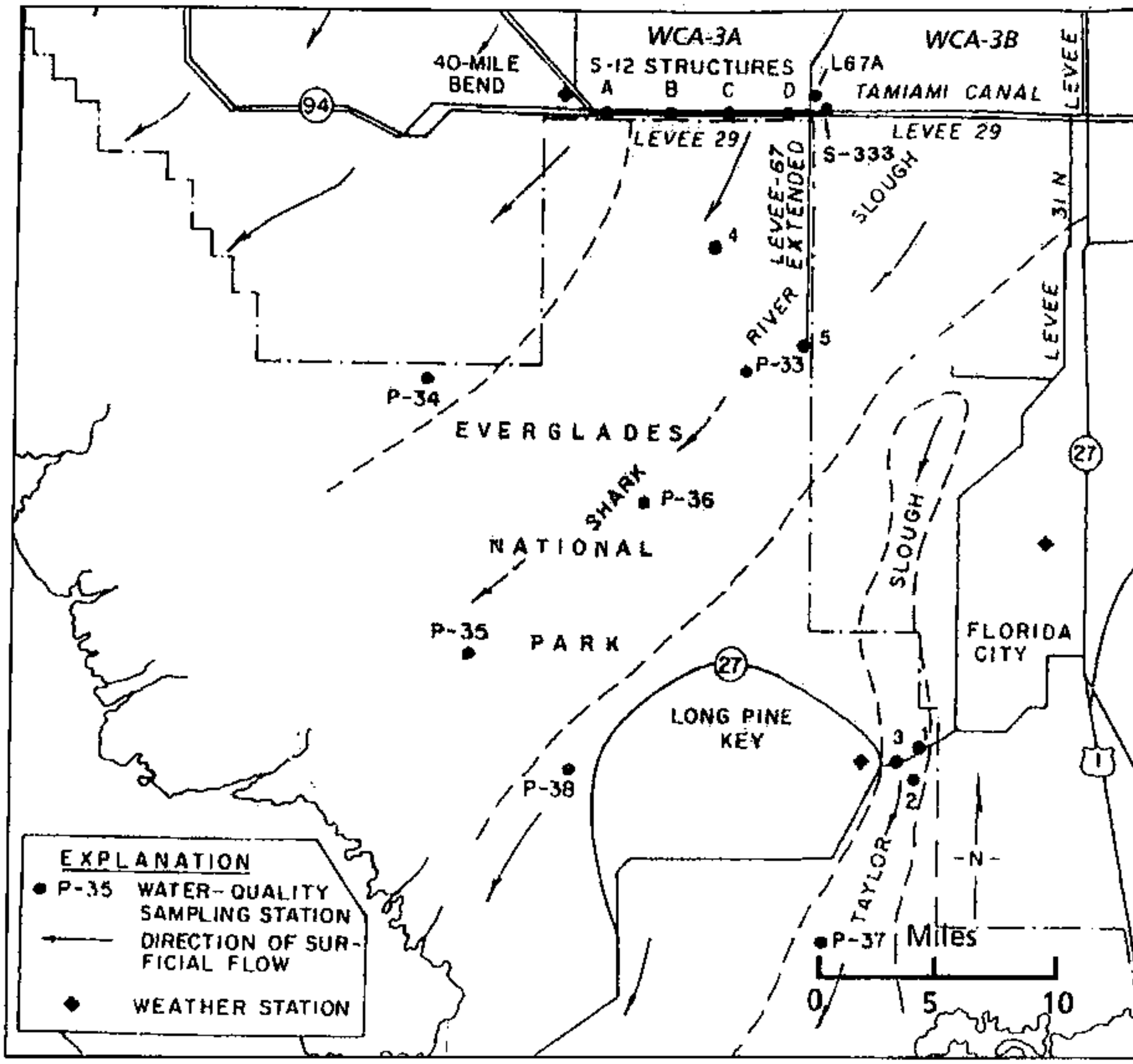


Table C-24. ENP 1985 Annual Averages
Table C-25. ENP 1986 Annual Averages
Table C-26. ENP 1987 Annual Averages
Table C-27 ENP 1988 Annual Averages

Water Quality Delivery to Shark River and Taylor Sloughs.

Macronutrients. Much of the published data is dated prior to or concurrent with development of the ENP Water Quality Criteria (1979) (**Appendix C, Tables C-16 through C-22).** Average nutrient concentrations at canal delivery inflow points and within Shark River Slough are generally lower than ENP criteria.

In their efforts to develop water quality criteria for delivery waters entering ENP, Rosendahl and Rose (1979) concluded that "the current quality of delivery waters to Everglades National Park [1970-1978] is sufficiently pure to maintain ecosystem integrity of this national wetland resource". The authors, however, noted that the park is highly vulnerable to water quality perturbations originating outside its boundaries and must have established criteria from which to compare and set limits on the quality of water entering the park. Analysis of data collected from two canal delivery inflow points (S-12C and L-67A) recorded a mean concentration of 0.033 mg/L for total phosphorus and 0.008 mg/L for phosphate from 1970-1978. Ammonia values for this same period of record averaged 0.089 mg/l, while nitrate and total nitrogen concentrations averaged 0.16 and 1.8 mg/L respectively (Rosendahl and Rose, 1979).

Analysis of a 1959-1977 data set collected by Waller (1982a) indicated that nitrogen and phosphorus concentrations within Shark River and Taylor Sloughs were typically low with total phosphorus concentrations averaging near 0.01-0.03 mg/L, most probably the result of uptake by biological processes (e.g., periphyton and marsh vegetation), organic detritus and exposed limestone which chemically binds phosphorus. Typical ammonia concentrations averaged 0.15- 0.38 mg/L, while nitrate values averaged 0.01-0.13 mg/L (Waller, 1982a).

Analysis of data collected from interior marsh sites (Shark River and Taylor Sloughs) as well as from canal delivery inflow points (i.e., the S-12's) from 1959-1977 detected no change in macronutrient concentrations at any station located within the park (Waller, 1982a). Reasons cited for the lack of any observed change were (a) the majority of nutrients were apparently assimilated by marsh vegetation, (b) for some stations, the sampling frequency was not uniform or contained a relatively short period of record and (c) seasonal variations in macronutrient content may have masked long-term trends (Waller, 1982a).

Likewise, Flora and Rosendahl (1982) reported that surface water nutrient concentrations within Shark River Slough and at canal delivery inflow points to Shark River Slough had not changed significantly during the period of their 1972-1980 study. Unlike specific conductance and dissolved ion concentrations which had increased appreciably as a result of the shift of surface water delivery from natural sheet flow to a canal delivery regime (see Flora and Rosendahl, 1981), ..."nutrient concentrations remained among the lowest in the South Florida system and appear to be largely unaffected by either man's change in the hydrological regime or on land use patterns...." Again, the major reason cited for the maintenance of the low nutrient levels was the extensive nutrient assimilative capacity of the Everglades marsh, and the absence of any direct man-made point source inflows (e.g., sewage effluents, urban runoff or non-point source inputs) in the immediate vicinity of Shark River Slough (Flora and Rosendahl, 1982).

In Shark River Slough, mean wet season concentrations of orthophosphorus and total phosphorus were low, with orthophosphorus values ranging from 0.001 to 0.013 mg/L . Mean wet season total phosphorus values ranged from 0.007 to 0.023 mg/L. Concentrations of orthophosphorus and total phosphorus were also low at canal delivery sites, ranging from 0.002-0.030 mg/L for orthophosphorus and from 0.013-0.060 for total phosphorus. Mean annual wet season ammonia concentrations in the sloughs averaged from 0.03-0.18 mg/L, while canal delivery inflow points averaged from 0.03-0.05 mg/L. Nitrate + nitrite concentrations within the sloughs averaged 0.07 mg/L while canal delivery points averaged 0.12 mg/L (Flora and Rosendahl, 1982).

Scheidt *et al.* (1987) presented the results of nutrient data collected from 1985-1987 for the marsh and canal delivery inflow points. Interior areas of the freshwater marsh sites exhibited low dissolved phosphate concentrations near the limits of chemical detection (i.e.,<0.004 mg/L), while dissolved nitrate concentrations typically averaged about 0.01 mg/L. During 1985 (a drought year), mean soluble phosphate concentrations at canal delivery inflow points (i.e., the S-12's) ranged from 0.010-0.017 mg/L while in 1986 concentrations averaged near the detection limit (0.004 mg/L). Average nitrate concentrations ranged from 0.02 to 0.122 milligrams per liter (mg/L) at the various S-12 gates. Scheidt *et al.* (1987) observed a trend of increasing nitrate levels from west to east along the Tamiami Canal with S-12D reporting the highest average concentration. Higher nitrate levels recorded at these eastern structures appear to be influenced by water conveyed by the L-67A Canal (Scheidt *et al.* 1987). In contrast, statistical analysis of a similar data set by Mattraw *et al.* (1987) showed no significant increase from west to east for either nitrate or total phosphorus. The highest average value for total phosphorus (0.019 mg/L) at S-12D is an order of magnitude lower than the MOA standard (0.24 mg/L). Comparison of

Table 48. Phosphorus Concentrations at Inflow Stations to Shark River Slough.

Site	Date		PO_4 (mg/l)	TP (mg/l)	Reference
Water Quality Standards Under COE/SFWMD/NPS MOA		x	0.02	0.24	Rosendahl and Rose, 1979
S-12A, S-12B, S-12C, L-67A and Bridge 53	1959-1977	x n	0.01 146	0.03 136	Waller 1982a
S-12A	5/70 - 9/71	range n	0.00-0.15 4	0.04-0.28 4	Joyner, 1973
S-12C and L-67A	1970-1977	x SD n	0.008 0.007 78	0.033 0.118 72	Rosendahl and Rose, 1979
S-12B S-12D S-333	1984	x x x	0.006 0.006 0.007	0.013 0.019 0.022	SFWMD, 1989 (unpublished)
S-12B S-12D S-333	1985	x x x	0.051 0.011 0.017	0.094 0.040 0.049	SFWMD, 1989 (unpublished)
S-12B S-12D S-333	1986	x x x	0.004 0.004 0.005	0.018 0.012 0.019	SFWMD, 1989 (unpublished)
S-12B S-12D S-333	1987	x x x	0.008 0.008 0.007	0.014 0.015 0.015	SFWMD, 1989 (unpublished)

Source: Based on data Compiled by CH2MHill

unpublished phosphorus data (SFWMD, 1989) to 1973-1983 values (Table 48) reveals similar phosphorus concentrations except during 1985 (a drought year). Both orthophosphate and total phosphorus were significantly higher in 1985, perhaps due to water supply deliveries to south Dade County during this period. Water was delivered from Lake Okeechobee and these flows generally bypassed the main marsh, although some flows did go to the S-12 structures since they were open. This situation would not occur under the current Rainfall Plan.

Ion-Related Parameters. Both Klein *et al.* (1975) and Flora and Rosendahl (1981) have documented an increase of specific conductance and major ion concentration in waters delivered to Shark River Slough from 1959 to 1977. Both studies have demonstrated gradual increases in specific conductance and ionic compounds in Shark River Slough at marsh site P-33. This increase was attributed to the shift of water delivery from natural sheet flow to a delivery canal regime. Specific conductance ranged from 250 to 290 umhos/cm in the early 1960s to over 500 umhos/cm in the late 1970s. More recent data should be reviewed to determine whether this trend is continuing.

Average values for conductivity, alkalinity, and all ions at delivery inflow points to the park have increased from west to east (S-12A to S-333) (**Appendix C-17**). However, all average values are below the current MOA standards. The 1970-1977 average values provided by Rosendahl and Flora (1979) are very similar to this later data set.

Metals. Data sets before 1977 show that all metal concentrations were well below ENP standards. The limited published data available do not allow any conclusions to be drawn (**Appendix C, Table C-18**).

Pesticides. Trace levels of pesticides have occasionally been detected in waters entering ENP (**Appendix C, Tables C-20 and C-21**). Available data for S-12 structures show no pesticides detected. Aldrin and heptachlor were detected once at S-333 Waller (1982a) reported results of USGS sampling for pesticides in the water column from 1966-1977. Only 24 detections were found in 1,700 analyses. The compounds detected were DDD, DDE, DDT, dieldrin, diazinon, and 2,4-D. All were found at low concentrations (maximums ranged from 0.01 to 0.05 micrograms per liter [ug/l]). Heptachlor epoxide was detected once (0.01 ug/l) at Cottonmouth Camp in ENP (McPherson, 1971) (**Appendix C, Tables C-20 and C-21**).

Other Parameters. Color is the only parameter in this group that displays an increasing trend from S-12A east to S-333 (Appendix C-19).

Estuarine Water Quality. Schmidt and Davis (1978) published a summary of estuarine (Whitewater Bay, Shark River Estuary, Buttonwood Canal) water quality information available for the Everglades estuary from 1879-1977 (**Tables 53 and 54**). This information is provided as an overview of historical data and sampling coverage for estuarine and marine areas within the planning area.

Pesticides in Canal Sediments and ENP Soils. Groundwater quality data from published literature were compiled to provide an overview of available reviewed information. Data for insecticides, herbicides, and PCBs in canal sediments and marsh soils have been compiled because of their potential effects on surface water and ground water quality (**Appendices C-31 through C-34**). There are some studies that have analyzed canal sediments from the same sites, but over different time periods. For example, S-12C was sampled in 1972-1974 (Waller and Earle, 1975), in 1982-1983 (Pfeuffer,1985), and in 1984-1988 (Pfeuffer, in press). Chlordane and the DDT family (DDE, DDD, DDT) were detected during the early study period but not in any of the subsequent studies. These compounds have been detected periodically at various sites in south Dade county since this work was completed. This should emphasize the need for a long term, continuous sampling program at the same sites.

Chlordane and the DDT family were detected often in sediments of the ENP water delivery sites, L-67A, S-12A, and S-333, collected from 1972 to 1983. Chlorinated hydrocarbons bind physically and chemically to bottom material (Waller, 1982) and would tend to remain in the sediments. More current samples at S-12C (1984-1988) show no evidence of these compounds (Pfeuffer, in press). However, the data reflect that the detection limits reported varied considerably over

Table 49. A Summary of Water Quality Measurements Reported from the Everglades Estuary Bay, Shark Slough Estuary and Buttonwood Canal) in Everglades National Park.

Date	Salinity (0/00)	Water Temp. (°C)	Dissolved Oxygen (ppm)	pH	Turbidity (JTU)	Chemical Date	Number of Stations	Number of Samples	Frequency of Measurement
1937-1938	26.9-17.5	---[a]	---	---	---	---	---	6	Irregular
Mar-May 1955-1957	14.0-40.82	19.0-33.0	---	---	---	(b)	4	187	Weekly
Aug-Jun 1957-1959	0.0-43.8	14.4-34.0	1.47-6.90	7.47-9.45	---	---	26	772	Monthly
Sep-Feb 1957-1962	0.0-39.8	16.0-32.5	0.0-6.39	7.7-8.3	---	---	25	559	Monthly
Apr-Mar 1962-1967	0.0-40.0	---	---	---	---	---	44	1,209	Monthly
Jan-Jun 1964-1965	15.5-45.2	15.8-34.0	---	---	---	---	1	89	Bimonthly
Jun-Jun 1963-1964	22.0-51.5	14.0-31.1	---	---	---	---	1	145	Weekly
1964-1975	0-28	15.5-33.0	4.3-10.4	6.4-8.5	0.0-27.0	(b)	9	158	Irregular
Oct-Sep 1965-1966	0.0-30.3	14.8-32.2	---	---	0.7-9.6	---	17	---	Monthly
Jan-Dec 1966-1967	23.5-37.4	16.4-31.8	---	---	---	---	1	66	Weekly
Dec-Feb 1966-1967	0.0-16.8	---	1.3-6.8	---	---	---	22	132	Monthly
Oct-Dec 1967-1968	0.0-27.4	---	---	---	---	---	3	12	Monthly
Sep-Nov 1968-1969	2.6-30.9	15.9-32.1	5.0-9.0	---	---	---	8	135	Monthly
May-Feb 1971-1972	18.0-36.9	21.0-29.9	---	---	---	---	6	236	Quarterly
Oct-Sep 1973-1974	0.1-41.6	13.2-31.8	0.0-9.5	5.8-8.5	0.4-41.0	---	26	416	Hourly Monthly
1966-1969	0.0-50.8	13.7-35.5	---	---	---	---	5	42	Irregular

[a] Dashes (---) Indicate data not reported; [b] Data Summarized in Table 45; Source Schmidt and Davis

Table 50. Summary of Chemical Water Quality Data Collected in Estuarine and Marine Waters of Florida Bay in Everglades National Park, 1945-1976.

PESTICIDES (ug/l)			
Chlorinated			
Aldrin	ND[a]	DDT	0.00-0.02
Dieldrin	0.00-0.05	Silvex	ND
Endrin	ND	Toxaphene	ND
Chlordane	ND	2,4-D	0.00-0.06
Lindane	ND	2,4,5-T	ND
DDD	0.00-0.01	Heptachlor	ND
DDE	0.00-0.01	Heptachlor Epoxide	ND
Nonchlorinated			
Ethion	ND	Diazinon	0.00-0.01
Trithion	ND	Methyl Parathion	ND
Methyl trithion	ND	Parathion	0.00-1.00
Malathion	ND		
CARBONATE SYSTEM (mg/l)			
Calcium Carbonate ($CaCO_3$)	11-315	Carbon dioxide (CO_2)	1.2-23
Bicarbonate (HCO_3^-)	104-439	Total inorganic carbon	16.8-72
Carbonate ($CO_3^=$)	0-17		
NUTRIENTS (mg/l)			
Nitrogen			
NH_3^-	0.00-2.8	Organic N	0.36-8.4
NO_2^-	0.00-7.0	Total N	0.02-9.3
NO_3^-	0.00-39	Kjeldahl N	0.23-2.0
NO_2^- and NO_3^-	0.00-6.3		
Phosphorus			
Total ortho P	0.00-1.1	Total ortho PO_4^{-3}	0.07-1.3
Total P	0.00-1.4	Inorganic PO_4^{-3}	0.00-3.5
Dissolved PO_4^{-3}	0.00-6.9	Dissolved PO_4^{-3}	0.01-0.10
Total PO_4^{-3}	0.00-15.5		
Carbon		*Silicon*	
Organic carbon	0-61	SiO_2	0.00-20
Total carbon	49-104	SiO_4^{-2}	0.00-7.0
METALS			
Dissolved			
Iron (ug/l)	0.00-810	Lead (ug/l)	0-5
Magnesium (mg/l)	1.1-1,800	Zinc (ug/l)	3-40
Strontium (ug/l)	0.2-9,500	Copper (ug/l)	2-40
Sodium (mg/l)	8.6-14,000	Cobalt (ug/l)	ND
Potassium (mg/l)	0.2-14,000	Chromium (ug/l)	0-1
Arsenic (ug/l)	0-10	Cadmium (ug/l)	ND
Aluminum (ug/l)	0.8-40	Calcium (mg/l)	7.3-1,910
Manganese (ug/l)	0-80		
Particulate (ug/l)			
Lead	0-8	Chromium	10
Manganese	0-70	Cobalt	ND
Arsenic	1	Copper	ND
Cadmium	ND	Zirconium	10
Total (ug/l)			
Aluminum	2-210	Nickel	0-47
Arsenic	0-12	Chromium	0-10
Cadmium	0-10	Cobalt	
Mercury	0.1-5.6	Lithium	0-0.15
Iron	0-3,100	Boron	1.1-6.0
Manganese	0-280	Copper	0-10
Lead	0-24	Zinc	1.5-60
NONMETALS (mg/l)			
Sulfate	0-3,870	Total Bromine	0-66
Chloride	13-25,000	Total Iodine	0-0.25
Fluorine	0-1.8		
MISCELLANEOUS PARAMETERS			
PCB (ug/l)	0.00-0.00	Biochemical Oxygen Demand (mg/l)	0-7.4
Dissolved Solids (mg/l)		Hardness (mg/l)	
Residue at 180°C	161-41,400	Calcium, Magnesium	105-8,700
Calculated	0.168-40,200	Non-carbonate	4-8,600
Sum of Constituents	139-45,400	Sodium Absorption Ratio	1.0-48
kg/m^3	0.2-35.0	Protein	0.0-18.5
ton/day	0.57	Carbohydrates	0.0-15.4
Oil and Grease (mg/l)	0-15		
Color (PCU)	5-160		

[a]Not Detected Source: Schmidt and Davis (1978)

time, compounding the difficulty in addressing possible temporal patterns. Some of this variability may be related to sampling procedures, or differences in analytical methods between laboratories.

Water control structure S-332, another ENP water delivery station, showed similar results. Samples taken in 1972-1974 (Waller and Earle, 1975) showed only trace amounts of DDD and DDE; samples taken in 1982-1983 (Pfeuffer, 1985) showed widespread presence of chlorinated hydrocarbons; and in 1984-1988 there were no detections of any pesticides in the sediments at S-332 (Pfeuffer, in press).

Few published reports of soil analyses within the ENP exist. McPherson (1971) noted the presence of the DDT family at Cottonmouth Camp. Waller (1982) reported trace amounts of chlorinated hydrocarbons (primarily the DDT family, chlordane, and dieldrin) at nearly every station sampled within ENP. The number, location, and sampling frequency of the stations used in Waller's (1982) pesticide analysis were unspecified.

Water Quality in the East Everglades. Water quality in the East Everglades is intimately tied with water that is delivered to ENP. The Rainfall Plan (MacVicar, 1985; Neidrauer and Cooper,1989), which is intended to restore sheet flow into NESRS, has increased the importance of maintaining good water quality in this area. Improperly planned and regulated development in the East Everglades could have significant impacts on area-wide water quality.

Water quality data analysis. The approach used to review trends of water quality delivery in this portion of the plan have been to compare data sets averaged over long time periods (i.e., 1955-1977, 1970-1977, 1978-1983 averages). This approach is not well suited to detecting changes over time. There are also a number of studies with limited samples and scope, which do not present enough data to substantiate any general comments about water quality trends. There is a need to examine data from sites that have a long, continuous period of record, that have been sampled at a reasonable frequency, and analyzed for the same parameters from year to year.

Most of the data sets currently available for long periods only present averages for the period of record at Shark River Slough water delivery sites (Waller, 1982a; Rosendahl and Rose, 1979; SFWMD, unpublished data). Only Flora and Rosendahl (1981, 1982) addressed water quality trends over time. They analyzed nutrient data for ENP water delivery from 1972 to 1980 and found no evidence of water quality degradation. However, they did find increased specific conductance and dissolved ion concentration trends, which were attributed to development of the L-29, L-67, and Miami canals. There are no detailed published analyses of recent water quality. More recent data needs to examined.

To detect any trend of water quality degradation in water delivered to the ENP, as a minimum, data must be examined on a yearly basis. The water quality information currently being collected by the District and NPS can be used for this purpose. Water delivery sites at the north end of ENP (S-12A, S-12B, S-12C, S-12D, S-333) have been continuously monitored since 1978; sites within the C-111 Basin (S-176, S-177, S-178, S-18C) have been monitored since 1983; and the delivery site into Taylor Slough (S-332) has been monitored since 1983. In addition, there are several ENP marsh sites which have continuous records since 1985. Analysis of water quality trends within the ENP over the past decade is needed.

Ideally, all sites where water quality affects the ENP planning area should be examined individually. This includes S-332 for Taylor Slough; L-176, L-177, L-178, and S-18C for the C-111 Basin; and the S-12 structures for the northern boundary of the study area. Current published water quality data for the Taylor Slough Basin are rare after 1974; for the C-111 Basin, data are virtually nonexistent. Water quality monitoring programs in these areas should be expanded.

7. Plant Communities

Terrestrial Vegetation.

Historical Vegetation Accounts. The vegetation patterns within Everglades National Park are thought to be approximately 5,000 years old. The oldest sediments, which contain remnants of plant species which occur today in the Everglades, have been dated to 5,000 years (± 100 years) before present (B.P.) (Gleason *et al.* 1984). During this time period, sea level rose approximately 4 meters to its current state (Scholl and Stuiver, 1967; Robbin 1984). The previous vegetation can only be inferred, but was probably much more xeric, with little or none of the existing wetland vegetation types (Watts, 1971).

The earliest descriptions of Everglades plant communities are qualitative and extremely sketchy. Later historical accounts include native and American plant names, and describe elements that relate to the present vegetation. The earliest written descriptions date to the mid-1500's, when Alvar Nunez Cabeza de Vaca recounted aspects of the natural history. The word "everglades" was apparently derived from a phrase coined by British geographer Vignoles in 1823, who used the words "Never Glade" to describe the large expanse of non-forested area. This phrase was reduced to Everglades and has appeared on maps since the early 1800s. The Seminole Indian name for the Everglades is "Pa-hay-okee", which translates roughly to grassy lake (Douglas, 1947).

As the southern Everglades become more accessible in the late 1800s there were attempts to inventory the species and define the plant associations. Hugh Willoughby traversed the area in 1898, going up Shark River then crossing over to the Miami River. Willoughby's photographs of the area showed sawgrass marshes, hardwood tree islands, and open water prairies. Angelo Heilpren (1887), Harshberger (1914), and Harper (1927) described Everglades communities, but probably never visited that area of the southern Everglades which is now the ENP.

Recent Vegetation Studies. The two most important early works describing the vegetation of the park were done by John Kunkel Small and John Henry Davis. Small visited the area of the park many times for his treatment of the flora of the southeastern United States (Small, 1932). In addition to identifying, classifying, and often naming the plants of the area, he described Royal Palm Hammock (Small, 1916) and cypress swamp areas (Small, 1933). In his book, *From Eden to Sahara*, (Small, 1929) chronicled what he observed to be destruction of Everglades vegetation due to dry season fires, collection pressures, and other human-induced changes. Davis (1943a,b) constructed the first vegetation map of the Everglades; discussed the ecological relationships among the vegetation, soils, and hydrologic conditions of a site; and depicted the successional relationships of the plant communities.

More recent descriptions of the Everglades vegetation have augmented these resources. Egler (1952) described the southern Everglades communities and theorized that fires played a dominant force in determining the relative abundances of graminoid and forested communities. Robertson (1953) was the first to quantitatively define the relationship of fire to the upland pine forests. Robertson (1955) also quantitatively related the plant associations to the avian populations. Craighead (1968) provided detailed lists of plant species by communities in the park, and described the importance of the alligator, hurricanes, soils, and fires to shaping the vegetation patterns (Craighead, 1971). Alexander and Crook (1984) also listed plant species occurrence within a number of square mile quadrants within the park, and evaluated shifts in boundaries between vegetation zones during the period 1940 through 1970. Hofstetter (1976) investigated the effects of fire on the pineland ecosystem. A review of the effects of fire on systems of south Florida was done by Wade *et al.* (1980), and included all of the major plant communities Everglades.

With the establishment of the South Florida Research Center (SFRC) at ENP in 1976, the park staff has been the source of most of the recent descriptions of the Everglades vegetation. Loope (1980) provided an extensive bibliography of south Florida botany. Avery and Loope (1983) provided a preliminary list of plants found within the park and also detailed information on rare and threatened species (Loop and Avery, 1979). Olmsted *et al.* (1980) mapped and inventoried the vegetation of Taylor Slough within the park, and did similar inventories of the mangrove area (Olmsted *et al.* 1981) and Long Pine Key area (Olmsted *et al.* 1983). Snyder (1986) investigated the effects of wet and dry season burns on the rockland forest. Gunderson *et al.* (1987) mapped the area of Shark River Slough using LANDSAT Thematic mapper data. Gunderson *et al.* (1986) reported on flood tolerance of common hardwood species. Gunderson, 1989 attempted to quantify hydroperiod characteristics in wetland communities of the park.

Phytogeographic Relationships. The origin of the flora of the ENP Planning Area can be traced to four sources: tropical, temperate, endemic, and exotic. Native tropical species of the park are primarily from the Caribbean region of the neotropics, with many plants from the Antillean areas. Propagules of these species are thought to have crossed the saltwater carried by hurricane winds or migrating birds, or were able to tolerate some period of saline inundation. The temperate flora is composed of species found throughout the coastal plain of the southeastern United States. The endemic taxa consist of species and subspecies that have evolved in unique habitats of southern Florida and are found nowhere else in the world. The exotic plants of the ENP are species that have been introduced into southern Florida for ornamental and horticultural purposes, but were so well adapted to conditions that they became naturalized.

Avery and Loope (1983) prepared a preliminary checklist of the vascular plants of the ENP and enumerated some 830 species. By their accounts, the flora is mostly tropical in origin. Temperate species are next in abundance, followed by exotic or non-native plants and endemic taxa. They identified 141 exotic plants in the ENP, or about 17 percent of the total. Robertson (1953) counted 122 taxa considered endemic, but later work by Avery and Loope (1980) refined the number of endemics to 65 taxa, or about 8 percent of the total plants in the ENP.

The plant taxa of the park represent 147 families and roughly follow the distribution of plant families reported by Long and Lakela (1971) in their description of the flora of tropical Florida. Of the angiosperms, 100 of the families are in the *Dicotyledoneae* and 29 are in the *Monocotyledoneae*. Of the remaining families, four are gymnosperms and 14 are ferns and their allies.

The plant family with the largest number of taxa in the ENP is the Poaceae, with 101 taxa, followed by the *Asteraceae* (77 taxa). Other well-represented families are the *Fabaceae* (54), *Cyperaceae* (45), *Orchidaceae* (35), and *Euphorbiaceae* (35). These families represent flora that is herbaceous and tropical.

Description of Plant Communities. The native plant communities of the Everglades are classified by major environmental determinants to vegetation distribution: topography, hydrology, and salinity. The three major vegetation groups are the upland vegetation complex, the freshwater wetland complex, and the saline communities (**Table 51**). The dominant species in each of the major plant community types are listed in **Table 52**.

Table 51. Native Plant Communities of the Everglades Grouped by Major Ecological Classes.

<u>Community Categories</u>

I. Upland Communities
- A. Rockland Pine Forests
  - 1. Low stature hardwood understory
  - 2. Tall hardwood understory
- B. Tropical Hardwood Hammocks
  - 1. Mature phase
  - 2. Successional, scrub phase

II. Wetland Communities
- A. Freshwater Wetlands
  - 1. Forested Communities (Tree Islands)
    - a. Bayheads
    - b. Willow heads
    - c. Cypress Forests
  - 2. Herbaceous Associations (Marshes and Prairies)
    - a. Sawgrass Marshes
      - i. Tall Stature
      - ii. Intermediate Stature
    - b. Wet Prairies (peat)
      - i. Eleocharis Flats
      - ii. Rhynchospora Flats
      - iii. Maidencane Marshes
    - c. Wet Prairies (marl)
  - 3. Little or no emergent vegetation
    - a. Ponds and Creeks
    - b. Sloughs
- B. Saline Wetlands
  - 1. Forested Wetlands
    - a. Monospecific Forests
    - b. Mixed Mangrove Forests
  - 2. Herbaceous Associations
    - a. Salt Marshes
    - b. Coastal Prairies

Groups derived from classes of Davis (1943a), Loveless (1959) and Gunderson and Loftus (In Press).

The upland complex includes pine forests, tropical hardwood hammocks, and former agricultural areas. Within the ENP, the uplands are primarily restricted to central areas in and around Long Pine Key (**Figure 45**). In the EEA, the upland areas have been largely converted to agricultural and residential land uses.

The freshwater wetland complex comprises three types of forested associations (bayheads, willow heads, and cypress forests) and three major groups of graminoid communities (sawgrass marshes, wet prairies, and open water sloughs). The freshwater wetlands of the ENP are in the two major drainage basins Shark River Slough and Taylor Slough.

Table 52. Plant Taxa in Vegetation Communities of the Everglades System.

Community	Species (D = Dominant species)	Growth Form
Ponds, Slough	(D) white water lily (Nymphaea odorata)	floating aquatic
	(D) floating heart (Nymphoides aquatica)	floating aquatic
	spatterdock (Nuphar luteum)	floating aquatic
	bladderwort (Utricularia foliosa)	submerged aquatic
	(Utricularia purpurea)	submerged aquatic
	water hyssop (Bacopa caroliniana)	submerged aquatic
	arrowhead (Sagittaria lancifolia)	emergent aquatic
	pickerel weed (Pontederia cordata)	emergent aquatic
Sawgrass Marsh Tall stature	(D) sawgrass (Cladium jamaicense)	emergent sedge
	Justicia angusta	emergent herb
	spikerush (Eleocharis cellulosa)	emergent rush
	cattail (Typha latifolia)	emergent aquatic
Intermediate Stature	(D) sawgrass (Cladium jamaicense)	emergent sedge
	swamp-lily (Crinum americanum)	emergent herb
	arrow arum (Peltandra virginica)	emergent herb
	spider lily (Hymenocallis latifolia)	emergent herb
	shy leaf (Aeschynomene pratensis)	emergent herb
	Everglades morning glory (Ipomea sagittata)	vine
Wet Prairies (peat) Eleocharis Marshes	(D) spikerush (Eleocharis cellulosa)	emergent rush
	(D) spikerush (Eleocharis elongata)	emergent rush
Rhynchospora flats	(D) beakrush (Rhynchospora tracyi)	emergent sedge
	water rush (Rhynchospora inundata)	emergent sedge
Maidencane flats	(D) Maidencane (Panicum hemitomon)	emergent grass
	water paricon (Paspalidium geminatum var. paludivagum)	emergent grass
	swamp lily (Crinum americanum)	emergent herb
	water hyssop (Bacopa caroliniana)	submerged aquatic
	arrowhead (Sagittaria lancifolia)	emergent herb
	water drop-wort (Oxypolis filiformis)	emergent herb
Wet Prairies (Marl)	(D) sawgrass (Cladium jamaicense)	emergent sedge
	(D) muhly grass (Muhlenbergia filipes)	emergent grass
	narrow beardgrass Schizachyrium rhizomatum	emergent grass
	white-top sedge (Dichromena colorata)	emergent sedge
	black-top sedge (Schoenus nigricans)	emergent sedge
	Aristida purpurescens	emergent grass
	Panicum tenerum	emergent grass
	Rhynchospora divergens	emergent sedge
	Rhynchospora microcarpa	emergent sedge
Swamp Forests	(D) red bay (Persea borbonia)	tree
	(D) sweet bay (Magnolia virginiana)	tree
	(D) dahoon holly (Ilex cassine)	tree
	(D) willow (Salix caroliniana)	tree
	(D) wax myrtle (Myrica cerifera)	tree
	cocoplum (Chrysobalanus icaco)	shrub
	swamp fern (Blechnum serrulatum)	fern
	leather fern (Acrostichum danaeifolium)	fern
	red maple (Acer rubrum)	tree
	red mangrove (Rhizophora mangle)	tree
Willow Heads	(D) willow (Salix caroliniana)	tree
	wax myrtle (Myrica cerifera)	tree
	buttonbush (Cephalanthus occidentalis)	shrub
	sawgrass (Cladium jamaicense)	sedge
Cypress Forests	(D) cypress (Taxodium ascendens)	tree
	sawgrass (Cladium jamaicense)	sedge
	Schizachyrium rhizomatum	grass
	white top sedge (Dichromena colorata)	grass
Mangrove Forests	(D) Red mangrove (Rhizophora mangle)	tree
	(D) Black mangrove (Avicennia germinans)	tree
	(D) White mangrove (Laguncularia racemosa)	tree
	(D) Buttonwood (Conocarpus erectus)	tree

Source: Data Compiled by CH_2MHill.

Table 52. Plant Taxa in the Vegetation Communities of the Everglades System (Continued).

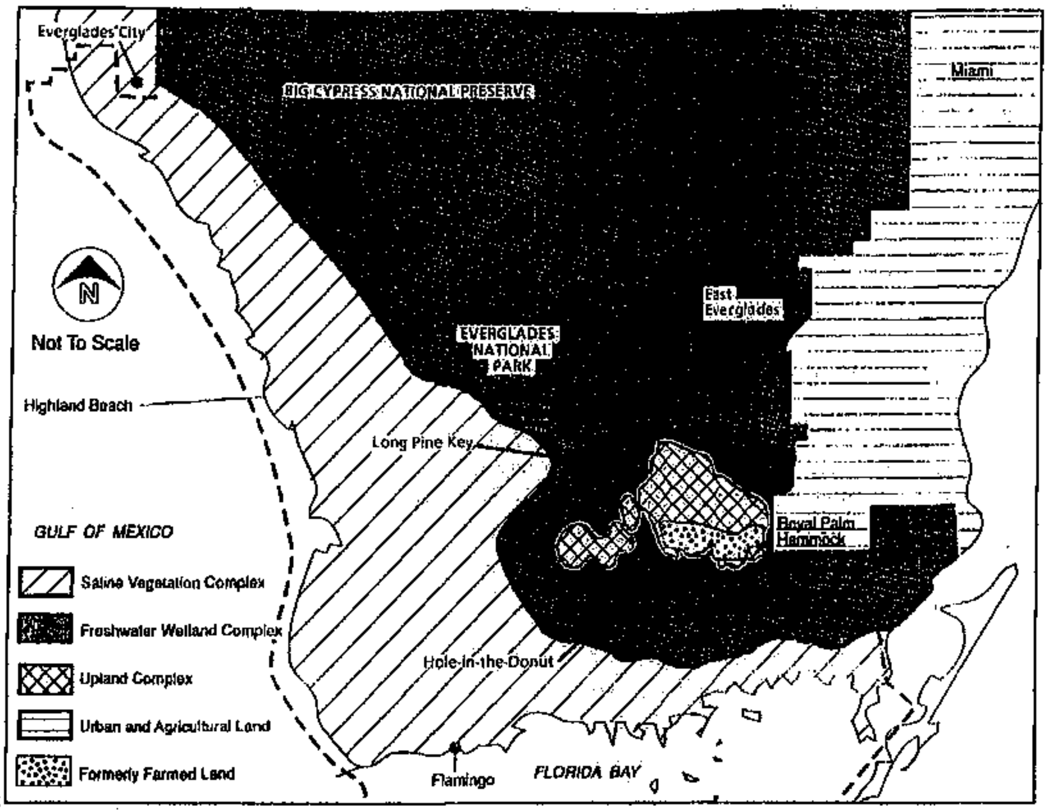
Community	Species (D = Dominant species)	Growth Form
Batis Marshes	(D) Batis maritima	emergent herb
	(D) Glasswort (Salicornia virginica)	emergent herb
	(D) Sea purselane (Sesuvium portulacastrum)	emergent herb
Coastal Prairies	(D) Gulf cordgrass (Spartina spartinae)	emergent grass
	(D) Sea-oxeye (Borrichia frutescens)	emergent herb
Salt Marshes	(D) Sand cordgrass (Spartina bakerii)	emergent grass
	(D) Gulf cordgrass (Spartina spartinae)	emergent grass
	(D) Black rush (Juncus roemarianus)	emergent rush
	(D) Fringe rush (Fimbrystylis castanea)	emergent sedge
Pine Forests	(D) South Florida slash pine (Pinus elliottii var. densa)	tree
	(D) Rough velvet seed (Guettarda scabra)	shrub
	(D) Randia aculeata	shrub
	(D) Varnish leaf (Dodonea viscosa)	shrub
	(D) myrsine (Myrsine floridana)	shrub
	(D) Willow bustic (Bumelia salicifolia)	shrub
Hardwood Hammocks	(D) strangler fig (Ficus aurea)	tree
	(D) gumbo-limbo (Bursera simarubra)	tree
	(D) Live oak (Quercus virginiana)	tree
	(D) wild tamarind (Lysiloma latisiliquum)	tree
	cabbage palm (Sabal palmetto)	tree
	hackberry (Celtis laevigata)	tree
	mulberry (Morus rubra)	tree
	citrus (Citrus spp.)	tree
	persimmon (Diospyros virginiana)	tree
	mahogany (Swietenia mahogani)	tree
	paurotis palm (Acoelorraphe wrightii)	tree
	Royal palm (Roystonea elata)	tree
Burned Hammocks	Florida trema (Trema micranthum)	tree
	saltbush (Baccharis halimifolia)	shrub
	wax myrtle (Myrica cerifera)	tree/shrub
	bracken fern (Pteridium aquilinum)	fern

Saline communities within the park include mangrove forests and salt-tolerant herbaceous marshes. The saline vegetation types are located in the southern portions of the ENP, bordering on Florida Bay and the Gulf of Mexico.

The total area of the non-marine portion of the ENP is approximately 340,00 hectares (839,800 acres) based on the Everglades Fire Management Plan (NPS, 1979), which is larger than the study area of the project. The saline vegetation complex covers about 182,00 hectares (449,500 acres), or about 54 percent of the area. The wetland vegetation complex covers approximately 150,000 hectares (370,500 acres), or about 44 percent. The upland vegetation complex is the smallest of major groups within the ENP, with only 8,000 hectares (19,800 acres), or 2 percent of the park area. Most of the East Everglades Area is characterized as part of the Everglades wetland vegetation complex, and the remainder is part of the upland vegetation complex.

Upland Vegetation Complex. The primary upland vegetation communities of the park are pine forests and tropical hardwood hammocks. Variations of these two forest types are generally due to effects of fire on the species composition and structure. The two forest types are primarily in and around Long Pine Key, the collective group of rocky outcroppings in the central area of the ENP. The upland complex once extended northward to the Miami area and covered about 64,780 hectares (160,000 acres) (Shaw, 1975). Long Pine Key is now the largest remnant of

Figure 45. Conceptual Distribution of Major Plant Complexes of the Everglades Region.



Source: Modified from Figure Compiled by CH2MHill

this community type; the remainder has been developed. The upland areas within the EEA have been converted to agricultural and land uses.

Pine Forests. The pine forests of the ENP are characterized by an overstory of south Florida slash pine (*Pinus elliotti* var. *densa*). Olmsted *et al.* (1983) reported mean densities of 250 to 660 stems/hectare (100 to 270 stems/acre), mean diameter at breast height (dbh) of 15 centimeters (6 inches), and mean heights of 12 to 18 meters (40 to 60 feet), in the Long Pine Key pine forests. Most of Long Pine Key was lumbered during the 1930s. The existing forests are approximately 50-year-old, second-growth stands.

Two types of pine forests were mapped by Johnson *et al.* (1983); those with low stature understory and those with well developed understory (Table 52). The distinction between these types can be explained by fire history, which will be discussed later under environmental relationships.

The most significant floristic feature of the rockland pine forests is the species richness of the understory stratum in the low-stature type. Loope *et al.* (1979) found 186 species in this association, making it the most diverse community in the ENP. Approximately 50 species of hardwoods, primarily West Indian in origin, are found in the understory (Taylor and Herndon, 1981). The understory plants in these forests only attain heights of 2 meters (6.6 feet). Dominant hardwoods include rough velvet seed (*Guettarda scabra*), *Randia aculeata*, varnish leaf (*Dodonea viscosa*), myrsine (*Myrsine floridana*), and willow bustic (*Bumelia salicifolia*) (Olmsted *et al.* 1983;

Taylor and Herndon, 1981; Snyder, 1986). Important palm species are cabbage palm (*Sabal palmetto*) and saw palmetto (*Serenoa repens*).

Grasses and forbs account for a small percentage of the total ground cover, but account for the bulk of the species diversity. Common graminoid species are narrow beardgrass (*Schizachyrium rhizomatum*) and *Andropogon cabanisii* (Olmsted *et al.* 1983). A number of endemic taxa are found only in the rockland pine forest. They include *Dyschoriste oblongifolia, Phyllanthus pentaphyllus, Borreria terminalis, Tragia saxicola, Chamaesyce porteriana* var. *porteriana, Jacquemontia curtissia, Melanthera parvifolia*, and *Forestiera segreata* var. *pinetorum* (Loope *et al.* 1979).

The pineland areas with the tall stature, hardwood understory contain the same hardwoods and palm species found in the lower stature pinelands, but the hardwoods attain heights of 8 to 10 meters (26 to 33 feet). The tall hardwood understory in this forest type typically has a closed canopy, resulting in few if any herbs and forbs in the ground cover.

Tropical Hardwood Forests. The broad-leafed evergreen, upland forests are locally called hammocks. These forests are dominated by West Indian species, and are the most diverse arboreal association in the ENP. At least 120 hammocks are found in conjunction with the pine forests of Long Pine Key (Johnson *et al.* 1983; Olmsted *et al.* 1983). One of the largest and most notable Hammock is Royal Palm Hammock, located at the edge of Taylor Slough and Long Pine Key. Royal Palm Hammock is noted for the emergent royal palm trees, *Roystonea elata* (Small, 1916). This hammock was first protected in 1916, when 770 hectares (1,900 acres) were set aside as Royal Palm State Park, forming the nucleus of ENP. Tropical hardwood hammocks also occur on elevated outcrops on the upstream side of some tree islands. These sites have a history of habitation by native American populations. Hammocks also are found in the saline zone of the park (Craighead, 1971; Russell *et al.* 1980).

The dominant overstory trees in the hammocks of Long Pine Key are live oak (*Quercus virginiana*), wild tamarind (*Lysiloma latisiliquum*), and gumbo limbo (*Bursera simaruba*). These trees attain heights of 18 meters (60 feet) and diameters of 2 meters (6.6 feet) (Olmsted *et al.* 1981). Other, less common, tree species in the overstory include sugarberry (*Celtis laevigata*), mastic (*Mastichodendron foetidissimum*), and mahogany (*Swietenia mahogani*)(in the southern hammocks).

A suite of species attain sub-overstory status and account for the tremendous stem density found in hammocks. Among these commonly found trees include willow bustic (*Bumelia salicifolia*), lancewood (*Nectandra coriacea*), many species of stoppers (*Eugenia* spp.), pigeon plum (*Coccoloba diversifolia*), marlberry (*Ardisia escallonoides*). Few plants are found on the ground because of heavy shading by the dense canopy. Most of the herbaceous flora are epiphytes, including vines, orchids, and bromeliads.

Hammocks that were recently burned or have histories of frequent past fires are in a successional, often scrubby phase. Hammocks with recurrent or severe fire damage are often colonized by *Trema floridana* and bracken fern (*Pteridium aquilinum*). Some hammocks in the East Everglades that were subject to frequent and severe fires now support Australian pine forests (Hilsenbeck *et al.* 1979).

Freshwater Wetland Vegetation Complex. The freshwater wetland vegetation complex of the Everglades is composed of forested and non-forested communities. The forested wetlands include bayheads, willow heads, and cypress forests. The non-forested or herbaceous wetlands of the park include sawgrass marshes, wet prairies, ponds, and open water sloughs. The communities are typically arrayed in a landscape mosaic of types, as shown by Rintz and Loope, 1979. and Olmsted *et al.* (1982).

Bayhead/Swamp Forests. The freshwater, broad-leafed, hydrophytic hardwood associations of the Everglades are also referred to as tree islands. The name is descriptive of the isolated, emergent trees surrounded by the lower stature marshes. Tree islands primarily comprise swamp forest vegetation, although some small areas of relatively higher elevation support mesic tropical hardwood vegetation. The larger tree islands within the ENP are in the shape of an elongated tear drop, generally oriented with the main axis parallel to the main axis of flow. The bayhead or swamp forest is the most common and abundant forested wetland type in the ENP.

Typically, a group of bay trees are co-dominants in this association, hence the name bayhead. Dominant canopy species include red bay (*Persea borbonia*), swamp bay (*Magnolia virginiana*), dahoon holly (*Ilex cassine*), pond apple (*Annona glabra*), and wax myrtle (*Myrica cerifera*). Other, less-common species include willow (*Salix caroliniana*) and strangler fig (*Ficus saurea*). These canopy species attain heights of between 8 and 10 meters (26 to 33 feet) (Olmsted *et al.* 1980). A dense shrub layer is generally found beneath the canopy, composed primarily of cocoplum (*Chrysobalanus icaco*) but including smaller individuals of the above-mentioned overstory species. Other plants in the shrub stratum include buttonbush, (*Cephalanthus occidentalis*) and the large leather fern (*Acrostichum danaeifolium*). Some areas of the understory are devoid of ground cover because of the dense shade of the overstory. Other areas are inhabited by herbaceous wetland species such as lizards tail (*Saururus cernuus*).

The soils in swamp forests are primarily gandy peat, with measured depths of 30 to 200 centimeters (1 foot to 6.6 feet) (Olmsted *et al.* 1980). The surficial soils are composed mainly of decomposing leaf material from the extant vegetation. The hydrologic regimes (duration of flooding) in these forests average between 1 month and 4 months. Many of the hardwood species cannot sustain prolonged flooding (Gunderson *et al.* 1988). Mortality has been observed in some areas where prolonged flooding occurred (Craighead, 1971).

Willow Heads. Stands of southeastern coastal plain willow (*Salix caroliniana*) are also called willow heads (Davis, 1943a; Loveless, 1959; and Craighead, 1971). These stands have a monospecific overstory and understory, with willow the dominant woody plant. Other, less-common, associated herbaceous taxa include phragmites (*Phragmites australis*), sawgrass, and flag (*Thalia geniculata*). Herbaceous vines such as *Sarcostemma clausa*, hemp-vine (*Mikania scandens*), and *Ipomea sagittata* are commonly found.

Willow heads are found on sites with a history of severe soil disturbance, such as a peat fire, lumbering, farming, or alligator excavation. Willow heads are common in the northern central areas of Taylor Slough (Olmsted *et al.* 1980). Large areas of willow are found along the western edges of the Shark Slough, where severe fires burned through bayheads during the early 1970s (Gunderson *et al.* 1987). Willow is also commonly found around alligator holes or ponds. Craighead (1971) reports that willow is much more widespread now than in previous times, due to changes in the hydrology and impacts of dry season fires. According to Hilsenbeck *et al.* (1979), willow thickets are ecologically important because they serve as feeding, resting, and roosting habitats for many of the herons, egrets, and other wading birds.

Cypress Forests. Cypress forests are relatively minor features of the ENP occurring east and west of the Long Pine Key area. Two types of forests occur, domes and cypress prairie. Both are dominated by pond cypress (*Taxodium ascendens*). Domes of pond cypress occur in bedrock depressions in northern Taylor Slough (Rintz and Loop, 1979). The domes are characterized by dense stands of pond cypress with diameters up to 50 centimeters (1.6 feet) and heights to 25 meters (80 feet). The domes with lowest soil surface elevations support little other flora, except perhaps a few aquatic species. Domes with higher soil elevations support many of the hardwood species found in bayheads including red bay, swamp bay, wax myrtle, and cocoplum, and have been called cypress heads (Olmsted *et al.* 1980).

Cypress prairies of the Everglades were first described by Small (1932). These forests have also been described as dwarf or hatrack cypress (Craighead, 1971). The cypress trees attain heights of less than 5 meters (16 feet) and diameters of less than 20 centimeters (8 inches). The trees are widely spaced. Understory plants include sawgrass, muhly grass, and other herbs and grasses.

Sawgrass Marshes. Sawgrass (*Cladium jamaicense*) is a ubiquitous, characteristic plant species of the Everglades freshwater marsh. Sawgrass-dominated marshes are the spatially dominant freshwater wetland plant community type both within the WCAs and ENP. Sawgrass is a rhizomatous, perennial sedge and not a grass as the common name implies. The plant is well adapted to the conditions of flooding and burning that occur in the Everglades. Although capable of surviving variable water depths from dry soil to flooding of the lower portions of the plant, sawgrass loses viability if high water levels are prolonged (Hofstetter and Parsons, 1979; Davis, 1989). Sawgrass also has low nutrient requirements (Steward and Ornes, 1975), a trait which allows survival in the oligotrophic waters of the Everglades.

The adaptations of sawgrass to fire have been well studied (Davis, 1943a; Loveless, 1959; Craighead, 1971; Forthman, 1973; Yates, 1974; Hofstetter and Parsons, 1979; and Wade *et al.* 1980). The leaves of sawgrass are extremely flammable (Wade *et al.* 1980), but the meristem is protected by spongy tissue (Conway, 1938) which is inflammable except under extreme drought conditions. With the meristem intact, regrowth is rapid (Forthman, 1973; Tilmant, 1975). Preburn structure (height and biomass) is attained within 2 years (Loveless, 1959).

Two types of sawgrass marshes occur in the ENP: tall stature or dense marshes, and intermediate or short stature sawgrass marshes (**Table 52**). Soil depths account for much of the observed difference in size. On sites with deeper accumulations of peat (over 1 meter), sawgrass attains heights up to 3 meters (10 feet). On sites with thinner organic soil, sawgrass normally attains heights of 80-150 centimeters (2.5 to 5.0 feet). Both types of marshes are dominated by sawgrass in terms of biomass and plant density. Few other species occur in the tall, dense marshes (Craighead, 1971) except some woody plants such as willow or pond apple. These establish in openings in or on the border of dense marshes. Only 14 other species have been found in association with sawgrass in the sparse sawgrass marshes (Olmsted and Loope, 1984). These include spikerush (*Eleocharis cellulosa*), *Bacopa caroliniana, Proserpinaca palustris* and *Ipomea sagittata*.

Wet Prairies. Wet prairies are a group of low-stature graminoid marshes. They are found over both peat and marl, with each soil type supporting distinct communities. Wet prairies occur in the ENP in the central areas of Shark Slough and Taylor Slough and in portions of the EEA.

Wet prairies are generally described by the dominant plant found in the associations. Loveless (1959) described the associations over peat as Eleocharis, Rhynchospora, and Maidencane flats. Craighead (1971) described them as spikerush and sedge flats. Common emergent aquatic plants in these wet prairies include spikerush (*Eleocharis cellulosa*), beak rush (*Rhynchospora tracyi*), maidencane (*Panicum hemitomon*), arrowhead (*Sagittaria latifolia*), and pickerel weed (*Pontederia lanceolata*). At least 25 taxa typically occur in these associations, but spikerush, beakrush, and maidencane dominate. In the WCAs, Goodrick (1984) found these three species comprise most of the mean 300 grams/square meter above-ground biomass. Submerged aquatics include ludwigia (*Ludwigia* spp.) and bladderworts (*Utricularia* spp.). Periphyton is a conspicuous, important feature of these associations, and will be discussed in the section on periphyton.

The wet prairies over marl are a conspicuous feature in the ENP. Marl prairies occur on the east and west margins of Shark and Taylor Sloughs and in the EEA, where bedrock elevations are slightly higher and hydroperiods shorter. These communities have been called the southern coastal marsh prairies (Davis 1943a), southeast saline Everglades (Egler 1952), marl Everglades (Kuchler, 1964), marl prairies (Harper, 1927; Werner, 1976; Olmsted and Loope, 1984) and *Muhlenbergia* prairies (Olmsted *et al.* 1980).

Most of the marl prairies in the ENP are dominated by the species muhly grass (*Muhlenbergia filipes*) and sawgrass. Other locally dominant species include the black top sedge (*Schoenus nigricans*), *Aristida purpurascens*, narrow beardgrass, and *Eragrostis elliottii*. Beak rush is common in the lower, wetter areas of the marl prairies. The marl prairies are a diverse association; Olmsted and Loope (1984) list over 100 species. The majority of these are herbaceous plants, and while they contribute greatly to the species diversity, they comprise less than 1 percent of the ground cover (Olmsted *et al.* 1980). Typically, the graminoid vegetation in the marl prairie community is less than 1 meter tall. Olmsted *et al.* (1980) found from 9 to 12 species/square meter. Above-ground biomass ranges from 50 to 100 grams per square meter, depending on soil depth, hydroperiod, and time since fire (Herndon and Taylor, 1986).

<u>Ponds and Creeks</u>. Ponds are small, typically less than 1 hectare (2.5 acres), open water areas scattered throughout the Everglades. Generally, little or no macrophytic vegetation is found in the ponds. The ponds are often bordered by spatterdock (*Nuphar luteum* subsp. *macrophyllum*), water lilies (*Nymphaea* spp.), fire flag (*Thalia geniculata*), pickerel weed (*Pontederia lanceolata*), and woody plants such as willow or primrose-willow (*Ludwigia peruviana*).

Creeks are open water areas found in the southern portions of the ENP, they occur at the interface of the freshwater and saline zones originating in the freshwater marshes, continuing through the mangrove forests, and terminating in Florida Bay, Whitewater Bay, and the Gulf of Mexico. The creeks are typically unvegetated, aquatic systems.

<u>Sloughs</u>. Slough communities are associations of floating aquatic plants. These associations are found on the lowest, wettest sites in the central portions of Shark River and Taylor Sloughs. Dominant macrophytes include white water-lily (*Nymphaea odorata*), floating hearts (*Nymphoides aquatica*), and spatterdock. The

remainder of the flora in these associations are composed of submerged aquatics and periphyton. The common submerged aquatics are the bladderworts (*Utricularia foliosa* and *U. biflora*). The submerged aquatics provide structure for attachment by periphyton and are a key component in what is described as the periphyton mat complex.

Periphyton. "Periphyton" describes the algal assemblages in the open-water areas. Periphyton is found in all the marsh and prairie associations but is most abundant in the slough community. Hydroperiod and water chemistry determine the species composition of periphyton (Swift, 1984). Calcareous blue-green algae and diatoms dominate in shorter hydroperiod sites, which are more alkaline and higher in carbonates (Browder *et al.* 1981). These algae precipitate calcium carbonate from the water, forming the calcitic mud or marl found in the marl prairies (Gleason, 1972). Different algal assemblages are found in sloughs and wet prairies over peat, sites with longer periods of inundation, and water characterized by relatively more nutrients and lower alkalinity. Desmids and filamentous green algae dominate the assemblages on these sites. The periphyton provide primary production which forms the basis of the detrital-based food web of the Everglades (Browder *et al.* 1982). The algae also influence oxygen levels in the free water as well as form biological mediators in the cycling of nutrients (Hunt, 1961; Brock, 1970; Wilson, 1974; Wood and Maynard, 1974; Gleason, 1972).

Saline Wetlands Vegetation Complex. The saline zone of the ENP consists of many forested and non-forested vegetation types. The area is tidally influenced, but soil salinity is the major determinant of the vegetation. Salinity in the zone ranges from freshwater in the upland waters during the rainy season, to hypersaline during extreme droughts. The zone parallels the coast and reaches a maximum width of 15 miles in the area of Shark River and tapers to the east and west **(Figure 45)** (Craighead, 1971). Russell *et al.* (1980) mapped the distribution of vegetation in the saline zone between Flamingo and Joe Bay. Olmsted *et al.* (1981) described the complex floristic composition of the saline communities.

Mangrove Forests. Four species of mangroves occur in the ENP: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*). Mangrove forests occur as monospecific stands dominated by one these four species and also as mixed forests including all combinations of the species. The understory stratum is not well developed in the mangrove forests, but some additional species that may be present in the understory vegetation include: antwood (*Bumelia angustifolia*), joewood (*Jacquinia keyensis*), christmas berry (*Lycium carolinianum*), rubber vine (*Rhabdadenia biflora*), moonflower (*Ipomea tuba*), and sawgrass.

The mangrove forest region of the ENP is a complex spatial mosaic of monospecific and mixed species stands (Russell *et al.* 1980). In addition to topographic and salinity gradients, disturbances such as lightning strikes, human disturbance (lumbering), and hurricanes probably account for the distribution of these associations. Craighead (1971) states that mangrove trees up to 1 meter (3.3 feet) in diameter and 250 years old existed prior to their destruction by major hurricanes in the last 50 years. Currently the largest trees are found in the areas along banks of rivers where organic soil depths are greatest. Along the freshwater margin of the mangrove forests, large areas of stunted red mangroves are found. At these sites, the mangroves only attain heights of 2 meters (6.6 feet).

Salt-Tolerant Herbaceous Communities. The herbaceous communities of the saline zone include *Batis* marshes, coastal prairies, and salt marshes. The salt marshes include Juncus marshes and Spartina marshes. The black rush (*Juncus roemarianus*) and fringe rush (*Fimbristylis castanea*) dominate the Juncus gulf cordgrass marshes. *Spartina* marshes with greater freshwater influences are dominated by sand cordgrass (*S. bakerii*); whereas in the more saline areas gulf cordgrass (*S. spartinae*) dominates. Common plants in the Batis marshes include *Batis maritima*, glass wort (*Salicornia virginica*), and sea-purselane (*Sesuvium portulacastrum*). Coastal prairies are dominated by gulf cordgrass and sea-oxeye (*Borrichia frutescens*).

Environmental and Successional Relationships. Although many factors explain the configuration and distribution of the vegetation communities, the major determinants are the hydrologic regime, soil type, and disturbance history. The disturbances influencing the communities are fire, hurricanes, frosts, and animals (Davis, 1943a; Loveless, 1959; Craighead, 1971). Some of the factors, especially soil type, hydrology, and fire regimes, are closely related and dependent upon each other.

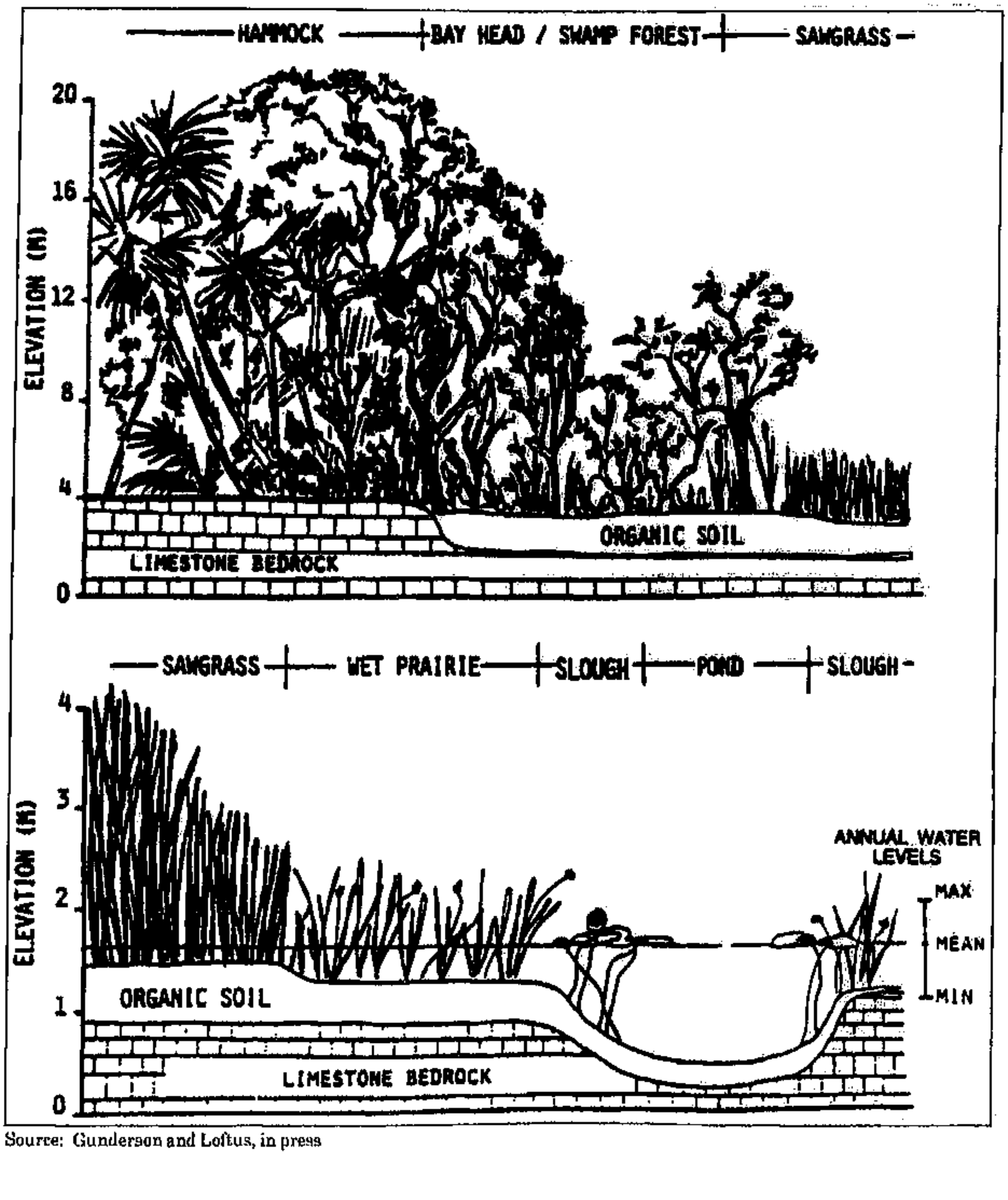
Hydrologic Regime. The two principle hydrologic determinants are hydroperiod characteristics (depth and duration of flooding) and water chemistry characteristics. The actual physical hydrology of a site is determined by its topography (soil surface elevation) and water budget.

The soil surface elevation is a function of the underlying bedrock topography and accumulations of organic soils. Soil surface elevations do not vary greatly in the ENP, with the range of relative elevations between the lowest and highest communities on the order of 1.5 meters (5 feet). Even though this range is small, elevation differences translate into greater differences in the hydrologic regime due to the temporal variability in rainfall inputs. Various ground elevation profiles contrast vegetation communities (Olmsted *et al.* 1980; Olmsted *et al.* 1983). Gunderson and Loftus (in press) present an idealized profile of the wetland vegetation types (**Figure 46**). However, no distinct quantitative differences in soil surface elevations among communities have been established due to the variation within a community type compared to the differences between communities. The wetland and upland community types (Table 52) can be ranked on an elevation gradient. From lowest to highest elevations, these are ponds, sloughs, wet prairies (peat), sawgrass marshes, tree islands, wet prairies (marl), pine forests, and tropical hammocks (**Figure 46**).

The hydrologic regime of the plant communities is driven by the annual rainfall pattern. The summertime rains cause water levels to rise during the summer months and reach the annual maximum levels by September and October. As rainfall decreases through the fall and winter months, water levels decline and reach annual minima during the spring months. The resulting inundation of the plant communities, is inversely related to the elevation rankings of the communities as listed above.

Davis (1943a) first related the influence of hydroperiod on the distribution of these communities. As long-term hydrologic data became available, quantification of the hydrologic regime within some of these plant communities was possible. Gunderson, 1989 studied water level records in five wetland communities of the ENP. The records showed historical hydropatterns did not statistically differ among community types due to the high year-to-year variability. The wettest associations are the ponds and slough communities, with year round inundation and mean annual

Figure 46. Generalized Profile of Plant Community Types of the Everglades, Showing Influences and Water Levels.



Source: Gunderson and Loftus, in press

depths of 30 centimeters (approximately 1 foot) (Gunderson, 1989). All of the remaining wetlands communities are inundated for at least some period during the year. The driest graminoid wetlands are the marl prairies, where inundation averages 3 to 7 months per year and mean depths average 10 centimeters (Olmsted *et al.* 1980). Hardwood tree islands, are inundated for shorter periods of time, averaging 4 to 5 months per year (Olmsted *et al.* 1980). The pine forests can become inundated for up to 1 month during extremely rare, very intense rain events. Tropical hammocks are rarely, if ever, inundated (Gunderson and Loope, 1981).

Salinity is one major aspect of water chemistry that influences the vegetation distribution. The border between the freshwater and saline wetlands is a large, dynamic zone determined by the equilibrium between the freshwater overland flow and the downstream tidal influence. Within the saline zone, the tolerance of each species of mangrove to soil salinity affects its distribution. Buttonwood is the least salt-tolerant of the four mangrove species and is found well inland. Red mangrove is tolerant of salinities from fresh water to sea water, and occurs inland to the middle of Taylor Slough (Rintz and Loope, 1979).

Most of the native vegetation of the Everglades is adapted to conditions of low nutrients, including the wetland vegetation such as sawgrass (Steward and Ornes, 1975; Davis, 1989) and the upland pineland vegetation (Snyder, 1986),

Soils. Each major plant community group has a distinct soil type. Craighead (1971) describes the soil types of the ENP as rocky soil, marl soil, or organic soil. The upland vegetation complex is primarily found on outcrops of the rocky soil type. Marl soils underlie the marl prairies, and organic soils are found in the remainder of the plant communities.

The rockland soils are outcrops of Miami or oolitic limestone and support the pine forests and tropical hammocks. Sand and marl are found in the depressions of the pitted rock substrate of the pine forests. A thin (10 centimeter) layer of decomposing leaf litter is found over the limestone of tropical hammocks (Olmsted *et al.* 1981).

Marl soil, or calcitic mud, has been called Perrine and Flamingo marls. It is generated by the blue-green algal mat found in the seasonally-inundated, short hydroperiod marshes.

The organic soils of the freshwater and saltwater vegetation are classified according to principal components. Red mangrove peat underlies much of the mangrove zone (Craighead, 1971). The soil in the slough communities has been described as Loxahatchee Peat (Gleason *et al.* 1984). It is composed mainly of remains of water lilies. The soil under sawgrass marshes is called everglades peat and is made up primarily of pieces of sawgrass in various forms of decay. The soil in willow heads is a black, plastic, mucky peat (Craighead, 1971). Gandy peat is the primary soil type beneath tree islands, containing much woody material and the decomposing leaves and other material from the extant vegetation (Davis, 1940; Craighead, 1971).

Natural Disturbances. Frequent and infrequent disturbances affect the vegetation of the Everglades, including lightning, freezes, hurricanes, animals, and fire (Craighead, 1971). Lightning and hurricanes have significant effects on the mangrove forests and less significant effects on other vegetation types. Freezes influence sensitive species in all communities. The alligator is the primary animal affecting the freshwater wetland associations. Fire plays a significant role in the ecology of all the non-mangrove associations.

Because of the high conductance of the saline soils in the mangrove zone, the electrical charge associated with a lightning strike will usually kill all the vegetation in area up to 1 hectare (2.5 acres) in (Craighead, 1971). Succession in these mangrove gaps is a poorly understood process.

Impacts associated with hurricanes occur as a result of the strong winds, high rainfall, storm surge, and increased wave action. Mangrove forests are affected by all of these processes whereas the inland vegetation types are affected by the wind and rain. Hurricane-force winds defoliate the vegetation and uproot trees of the woody associations. The high rains can produce some flood mortality. Massive mortality occurred in the ENP mangrove forests after hurricane Donna in 1960, when the storm surge and waves deposited a fine mud that suffocated the root systems (Craighead, 1971).

Fires have been a recurrent part of Everglades ecology as evidenced by the charcoal layers in the basal peats of the wetlands (Cohen and Spackman, 1984). Fires during the dry season consume the standing vegetation and can also burn the organic soils.

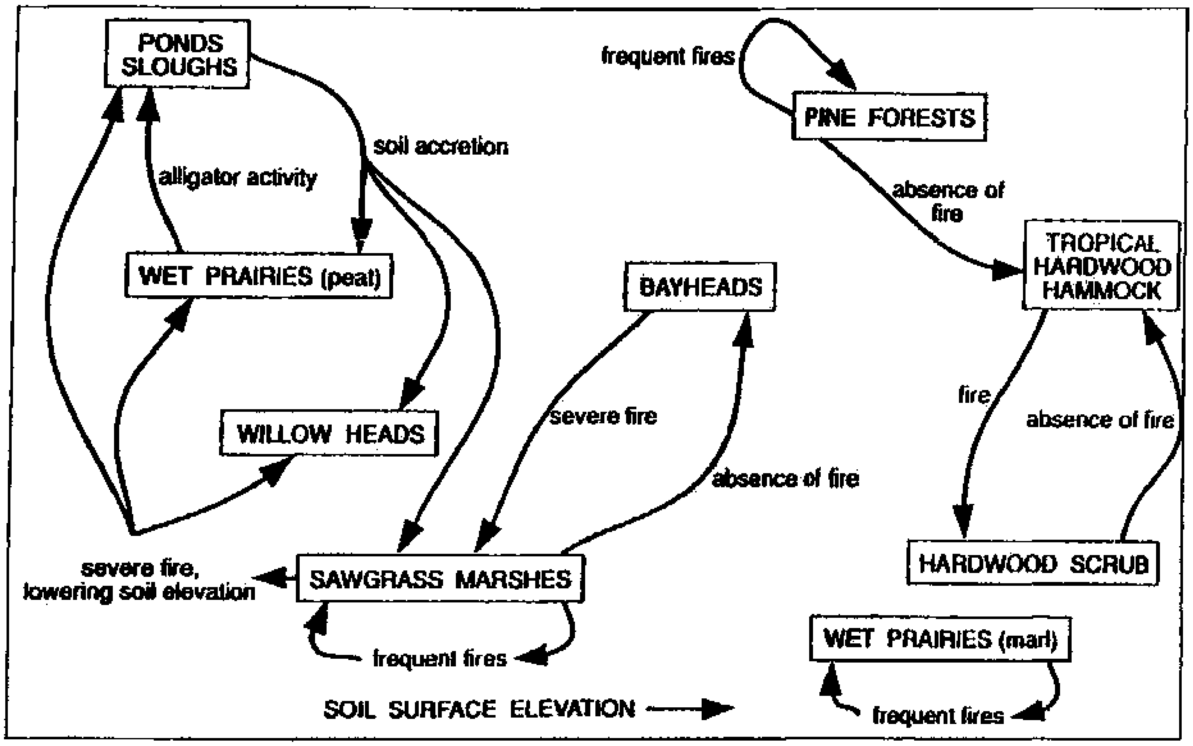
Survival of the rich endemic flora of the pine forests depends on an open canopy maintained by frequent fires (Robertson, 1953; Wade *et al.* 1980; Loope and Avery, 1979). The fires consume pine needle litter, standing grasses, palms, and hardwood leaves and stems (Snyder, 1986). Most of the pineland plants, except the pines themselves, resprout readily from protected meristems. The hardwood plants are therefore prevented from dominating the site, which can occur within 25 years in the absence of fire (Phillips, 1940; Alexander, 1967; Robertson, 1953; Hofstetter, 1976). Fires burn the pine forests on the average of once every 3 to 7 years (Robertson, 1953; Hofstetter, 1976; Taylor, 1981; Wade *et al.* 1980).

Tropical hardwood hammocks can burn during dry years, and most of the hammocks of Long Pine Key show evidence of having been burned within the last 40 years (Olmsted *et al.*, 1983). Robertson (1953) found that post-fire recovery of hammocks depends on recovery from undamaged root systems and regeneration from external seed sources. Flowering and fruiting of some pineland species can be stimulated by burning, whereas the flowering and fruiting of some hardwoods appears to be delayed in response to fire (Gunderson *et al.*, 1983).

The role of fire in the wetland complex depends on the ambient moisture conditions. Severe fires during drought conditions can consume the organic soils, lowering soil elevation and altering plant communities. The impact of fire on sawgrass communities has been well studied (Robertson, 1953; Forthman, 1973; Yates, 1974; Hofstetter, 1976; Werner, 1976; Wade *et al.* 1980). Sawgrass can burn over standing water, and regrowth is very rapid, reaching pre-burn heights and biomass within 2 years (Loveless, 1959; Forthman, 1973; Yates, 1974). Peat-consuming fires can result in the conversion of sawgrass marsh to *Eleocharis* flat (Craighead, 1971). Similar peat fires in the bayhead tree island communities during the early 1970s resulted in dominance by willow (Wade *et al.* 1980).

Since most of the observed natural changes in the vegetation of the ENP involve fire, successional relationships will be presented in context of fire effects and post-fire recovery. Davis (1943a) and Alexander and Crook (1984) present a successional scheme based on the concept that all communities would eventually succeed to a single community given the proper time and environmental conditions. Robertson (1955) stated that it was unlikely for some of the pathways to occur, since basic differences in soil type and elevation would not be changed by community processes. Olmsted and Loope (1984) indicate that the state of sea level as well as many of the above-mentioned disturbances account for the current distribution of vegetation patterns. Gunderson and Loftus (in press) present a hypothetical diagram that depicts the successional relationships among the communities which have been observed or reported in the literature. This diagram is presented with the addition of rockland pine forest (**Figure 47**).

Figure 47. Successional and Environmental Relationships Among Major Plant Communities of the Everglades.



Source: Modified from Gunderson and Loftus, In Press.

Threatened and Endangered Plant Species. Loope and Avery (1979) provided an excellent review of the ENP plant species that require special attention. They reviewed the existing state and federal lists of endangered and threatened plants and added their own information and ranking system on the status of plants within the ENP. **Table 53** summarizes the federal (U.S. Fish and Wildlife Service), state, and ENP status of the plant species of concern that occur within the ENP. Among the threats to these species are wildfire, illegal collecting, hurricanes, invasion of exotic species, and fire management programs (Loope and Avery, 1979). Although all plants within the ENP are protected under federal law, only two, *Euphorbia garberii* and *Cereus gracilus* var. *pinetorum*, are listed by the U.S. Fish and Wildlife Service as Endangered. The federal agency is considering listing at least 20 other plant taxa.

Tropical hammocks support the gratest number of taxa (59) listed by Loope and Avery (1979). Most of these are epiphytic bromeliads, orchids, and ferns.

Table 53. Status of Rare, Threatened, and Endangered Plant Species in the Everglades National Park (Modified from Loope and Avery, 1979).

Species	Federal Status[a]	FCREPA List[b]	Park List[c]
Psilotum nudum			5
Selaginella eatonii			2
Ophioglossum palmatum		E	1
Anemia wrightii			2
Polypodium plumula			2
Polypodium heterophyllum			4
Acrostichum aureum		R	5
Adiantum melanoleucum		R	1
Adiantum tenerum			1
Sphenomeris clavata			1
Tectaria lobata			1
Lomariopsis kunzeana			1
Zamia pumila		T	3
Digitaria pauciflora	2		2
Imperata brasiliensis			4
Schizachyrium gracile			4
Schizachyrium rhizomatum			5
Roystonea elata	1	R	1
Acoelorraphe wrightii			5
Thrinax radiata		T	3
Coccothrinax argentata		T	3
Tillandsia flexuosa		T	3
Catopsis berteroniana		R	3
Catopsis floribunda			1
Guzmania monostachia		E	1
Vanilla phaeantha			3
Vanilla barbellata		T	3
Spiranthes costaricensis			2
Erythrodes querceticola			2
Encyclia cochleata			3
Encyclia boothiana	2	E	1
Epidendrum nocturnum		T	3
Epidendrum rigidum			3
Polystachya concreta			3
Cyrtopodium punctatum		T	1
Govenia utriculata			2
Galeandra beyrichii			2
Maxillaria crassifolia		E	1
Brassia caudata	2	RE	1
Oncidium floridanum			1
Oncidium luridum			1
Oncidium carthagenense	2	RE	2
Macradenia lutescens			1
Peperomia floridana	2	E	3
Peperomia obtusifolia		R	4
Acacia pinetorum			3
Rhynchosia cinerea	2		3
Rhynchosia swartzii			2
Cassia deeringiana			4
Desmodium lineatum			3
Tephrosia florida			3
Aeschynomene pratensis var. *pratensis*	2		5
Galactia pinetorum	2		3
Linum carterii var. *carterii*	1		3
Alvaradoa amorphoides			1
Polygala boykinii var. *sparsifolia*	2		3
Stillingia sylvatica ssp. *tenuis*	2		4
Hippomane mancinella		T	3
Euphorbia garberii		E	1
Chamaesyce porteriana var. *porteriana*	2		4
Phyllanthus pentaphyllus var. *floridanus*	2		4
Tragia saxicola	2		4
Argythamnia blodgettii	2		1
Ilex krugiana		T	3
Calyptranthes zuzgium			1

Table 53. Status of Rare, Threatened, and Endangered Plant Species in the Everglades National Park (Continued).

Species	Federal Status[a]	FCREPA List[b]	Park List[c]
Myrcianthes fragrans var. *simpsonii*	2		5
Ludwigia spathulifolia			2
Jacquinia keyensis			3
Crossopetalum rhacoma			1
Hypelate trifoliata		T	1
Colubrina cubensis var. *floridana*			1
Gossypium hirsutum		E	3
Pavonia spicata			2
Passiflora sexflora			1
Rhipsalis baccifera		RE	2
Cereus gracilis var. *simpsonii*	E	T	3
Forestiera segregata var. *pinetorum*	1		3
Ipomoea microdactyla			3
Ipomoea tenuissima			4
Jacquemontia curtissii	2		4
Bourreria cassinifolia			1
Cordia sebestena			1
Lantana depressa			4
Verbena maritima	1		1
Elytraria caroliniensis var. *angusta*	2		4
Ernodea littoralis var. *angusta*		T	1
Melanthera parvifolia	2		4
Sachsia polycephala		E	4

[a] E= Endangered
T= Threatened
1,2= Taxa are under consideration for formal listing, Status 1 species are given higher priority for assessment than status 2 taxa.

[b] E= Endangered
T= Threatened
R= Rare
RE= Recently extirpated

[c] 1= Species of highest concern
2= Species have always been rare
3= Species with very restricted range,range reduced
4= Species with very restricted range, still rare within range
5= Species with very restricted range, still common within range

Notes: Federal status indicates listing by the U.S. Fish and Wildlife Service in the Federal Register. State list is from report by Ward *et al.* (1978) by the Florida Committee on Rare and Endangered Plants and Animals (FCREPA). Park list is from Loope and Avery (1979). Species given federal status are the only ones provided protection under regulatory programs.

Solution holes in hammocks support at least ten rare plant species. Species which are the rarest in this association are *Ophioglossum palmatum*, royal palm, *Catopsis floribunda, Guzmania monostachia, Encyclia boothiana, Cyrtopodium punctatum, Brassia caudata, Oncidium floridanum, Macradenia lutescens*, and *Calyptranthes zuzygium*. Some of these taxa, such as *B. caudata*, may be recently extirpated.

The flora of the pinelands includes 51 taxa of special concern (Loope and Avery, 1979). Many of these are endemic grasses and herbs found only in the rockland vegetation type. *Euphorbia (Chamaesyce) garberii*, a plant species that is classified as federally endangered, occurs in the pineland association. Other taxa of concern are *Alvaradoa amorphoides, Argythamnia blodgettii, Crossopetalum rhacoma, Hypelate trifoliata, Colubrina cubensis* var. *floridana, Passiflora sexflora, Bourreria cassinifolia, Verbena maritima*, and *Ernodea littoralis* var. *angusta*. Other plant communities support fewer taxa of concern. Wet prairies over peat have 9 species, mangrove forests have 11 species, and freshwater marshes have only one.

Exotic Plant Species. Even though over 140 exotic plant species occur in the ENP only a few threaten to invade and displace native plants. The National Park Service classifies exotic taxa as pest, potential pest, or innocuous for management purposes. The pest plants have large populations and pose the greatest threat of invasion. The woody plants that are well established in the East Everglades and are invading the native habitats include brazilian pepper (*Schinus terebinthifolius*), australian pine (*Casuarina* spp.), cajeput (*Melaleuca quinquenervia*), and shoebutton Ardisia (*Ardisia solanacea*) (La Rosa and Gunderson, in press). Problem non-woody plants include water hyacinth (*Eichhornia crassipes*), *Colubrina asiatica*, para grass (*Brachiaria mutica*) and *Reynaudia reynaudiana*. The genus of some of these plants will be used (lower case, not underlined) as a common name below.

Brazilian pepper, or schinus, poses one of the largest management problems in the ENP planning area because of its large populations and proven ability to invade a number of habitats. Until 1975, approximately 5,000 acres (called the Hole-in-the-Donut) in the southern part of Long Pine Key was farmed. This area now supports forests dominated by brazilian pepper, although shoebutton ardisia and para grass dominate locally, and is the largest concentration of exotic plants in the ENP. The farming practices of rock plowing and nutrient addition altered the physical and chemical aspects of the substrate, allowing schinus a competitive advantage over native species (Ewel *et al.* 1982; Meador, 1977). The schinus stand provides a large seed bank for dispersal into other ENP communities. Schinus will establish in pinelands, and will dominate the understory if the stand is not burned (Wade *et al.* 1980). Schinus can be controlled through the proper use of burning the pinelands (Loope and Dunevitz, 1981; Wade *et al.* 1980). Schinus has also been found in disturbed, ecotonal areas of the mangrove forests (Mytinger and Williamson, 1987).

Australian pine, or casuarina, was the first major exotic plant recognized as invading the ENP (Egler, 1952; Robertson, 1953). *Casuarina equisetifolia* formed a monospecific stand on Highland Beach in the ENP but was successfully removed through cutting and burning (LaRosa and Gunderson, In Press). Other species of casuarina are established in the southeastern panhandle of the ENP (Klukas, 1969), replacing the bayhead species (Craighead, 1971). This pattern also occurred in the East Everglades in an area north and east of the ENP which may soon be incorporated by the ENP.

Currently, no large stands of melaleuca are found in the ENP. Isolated individuals are scattered throughout the wetland sites. Large stands of melaleuca are found in the East Everglades along Krome Avenue, and are expanding into surrounding disturbed wetlands. Recent interagency control programs have eliminated melaleuca within a 3-mile zone along the northern and eastern borders of the ENP.

Other, less common, introduced exotic plants include water hyacinth, shoebutton ardisia, and colubrina. Water hyacinth occurs in the L-67 extension canal in the northern ENP areas. This floating aquatic has spread into adjacent marshes but does not appear to have yet displaced native associations. Shoebutton ardisia occurs in and around the Hole-in-the-Donut and Royal Palm Hammock, where it was introduced as a landscape ornamental. Recent control programs have mechanically removed many plants (Whittaker, SFRC, personal communication). Colubrina occurs in the mangrove areas of the ENP where it grows as a vine on top of mangrove trees (Olmsted *et al.* 1981).

Recent Vegetation Changes. Recent changes in Everglades vegetation have resulted from human-induced changes in major environmental factors. The changes are associated with altered hydrologic regimes, substrate alteration and modified fire patterns (Craighead, 1971; Alexander and Crook, 1984; Gunderson *et al.* 1987). In a study of the plant communities of the East Everglades Area, Hilsenbeck *et al.* (1979) listed 17 vegetation types as "deflected successions" resulting from major human-induced changes in Everglades plant communities (Table 54).

Table 54. Plant Community Types Characterized as Deflected Successions in East Everglades Area Resulting from Man-Induced Activities.

Fire-related recovery vegetations
Bayhead recovery communities
Cypress dome recovery communities
Hammock forest recovery communities
Exotic species in natural secondary successions
Cajeput colonization of sawgrass communities
Brazilian pepper, cajeput, and Australian pine colonization of muhly prairies
Brazilian pepper and Australian pine invasion of hammock-bayhead recovery communities
Cajeput forests
Australian pine forests
Agriculturally-induced successions
Rockplowed prairies without farming effects
Rockplowed prairies with farming effects
Grove plantings
Annual recovery vegetation on farmlands
Napier grass communities
Saltbush-Brazilian pepper communities
Brazilian pepper monocultures
Brazilian pepper-guava forests
Willow-monoculture on abandoned farmland
Sawgrass-cypress-bayhead analogue communities

(Modified from Hilsenbeck *et al.*, 1979)

Vegetation changes in the upland areas of the ENP are primarily due to modifications in the fire regime. Following the lumbering in 1930-1940, the pine forest apparently did not burn for several years. Robertson's (1953) work resulted in a prescribed fire program in the late 1950s. Since that time, the management program has burned most of the areas of pineland habitat. A few isolated stands have not been burned in 25 years, and now are dominated by hardwoods (Wade *et al.* 1980). Taylor and Herndon (1981) determined that for the 22-year period of prescribed burning, hardwood abundance was fairly constant. They found the density of some species (*Dodonea viscosa*, winged sumac (*Rhus copallina*), and *Tetrazygia bicolor*) increased in response to the winter burning regime, while other species (*Hypelate trifoliata, Jacquinia keyensis, Byrsonima lucida*, and *Ilex krugiana*) decreased in stem density or disappeared. Most Long Pine Key hammocks show evidence of burning during the past 40 years, and recovery within 25 years (Loope and Urban, 1980).

Changes to the wetland communities have resulted from changes in the hydrologic regime, particularly disruption of overland flow into the ENP. Wetland marshes and prairies in northern Taylor Slough are probably drier due to the canals and development of upstream watershed (Craighead, 1971). Concomitant with the drying out of these wetlands is an increase in fire frequency, which also alters species composition. One such change is the apparent increase in the abundance of muhly grass (*Muhlenbergia filipes*) in Taylor Slough. Early botanists (Small, 1932; Davis, 1943a) did not recognize this species as a dominant plant, yet later work by Werner (1976), Olmsted *et al.* (1980), Herndon and Taylor (1986) showed this plant is a co-dominant with sawgrass. Atwater (1954) was the first to indicate muhly grass was dominating in this area. Herndon and Taylor (1986) indicate muhly grass may be increasing as a result of a frequent burning regime, which decreases sawgrass density. Another change in northern Taylor Slough is the invasion of woody plants into the graminoid wetlands. Olmsted *et al.* (1980) indicated red bay, dahoon holly, and wax myrtle are now found in the muhly prairie association.

During droughts, severe fires consume organic soils of wetland associations. Severe fires burned the bayhead tree islands along the eastern portion of Shark Slough during 1971 and 1974, consuming both the vegetation and organic soil. These areas are now colonized by monospecific stands of willow (Craighead, 1971).

Prolonged flooding also can result in vegetation changes. Water levels in central Shark Slough were apparently high during the mid-1970's and contributed to the observed "decadence" or decrease in culm density and stature of sawgrass described by Hofstetter and Parsons (1979). These sawgrass stands have apparently returned to a healthy status (Wade *et al.* 1980). Many hardwood species in the bayhead association are sensitive to prolonged flooding (Gunderson *et al.* 1988). Craighead (1971) attributed mortality of hardwoods along the L-67 extension canal to flooding events during the late 1960s. Similar effects were noted in WCA-2A (Worth, 1988) and WCA-3A (Zaffke, 1983).

Because most Everglades wetland vegetation evolved under conditions of low nutrients, it could be altered by increases in nutrient concentrations. In historically similar wetland communities of the Water Conservation Areas (northern Everglades), increased nutrient levels, along with physical disturbance and hydroperiod alteration, are thought to have caused a shift in vegetation from sawgrass to cattail dominance (Davis 1991). The periphyton community in these areas has also shifted, with native calcareous blue-green and diatom algal species being replaced by pollution tolerant flora (Swift and Nichols, 1987).

8. Wildlife and Fauna

Historical Overview A reference list of the major studies of Everglades fauna is presented in **Table 55.** The early works which described the fauna of the area now in the ENP focussed on the avifauna and large mammals. A wildlife reconnaissance of the area to become the ENP was done by Daniel Beard (Beard, 1938), who later became the first superintendent. Robertson and Kushlan (1984) state that the earliest descriptions of birds in southern Florida can be traced to Titian Peale's visits to the Florida Keys in 1824. Howell (1932) and Sprunt (1954) are important early references on birds of the area. Common birds and mammals were listed by Willoughby (1898), Harper (1927) and Davis (1943a). Schwartz (1952) was the first to summarize the mammals of south Florida. Robertson (1955) correlated land-bird populations to vegetation communities within the ENP. The reptiles and amphibians of south Florida were enumerated by Duellman and Schwartz (1958).

Most recent studies of Everglades fauna have been done on the birds, especially wading birds, although several studies have detailed the ecology of reptiles, especially the alligator and various mammals. Basic habitat and avian ecology relationships were investigated by Robertson (1955), and Robertson and Kushlan (1984). Studies on specific bird species include work on the Cape Sable Seaside Sparrow (*Ammospiza maritima mirabilis*) by Werner (1976) and Bass and

Table 55. Major Studies of Everglades Herpetofauna, Avifauna, and Mammals*

Group	Author(s) (date)	Subject
Reptiles/ Amphibians	Duellman and Schwartz, 1958; Dalrymple (in press)	Composition, habitat relationships
	Ligas, 1960	Pig frog (*Rana grylio*) biology
	Craighead, 1968; Kushlan, 1974; Kushlan and Kushlan, 1980a	Alligator Biology
Birds	Robertson, 1955	Land/bird vegetation relationships
	Robertson and Kushlan, 1984	Composition, ecology, and zoogeography
	Werner, 1976; Bass and Kushlan, 1982a	Biology/ecology of Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*)
	Kushlan, 1977, 1979a	White Ibis (*Eudocimus albus*)
	Ogden et al., 1976, 1978	Wood Stork (*Mycteria americana*)
	Beissinger and Takekawa, 1983; Sykes, 1983	Snail Kite (*Rostrhamus sociabilis*)
	Sprangers, 1980	Boat-tailed Grackle (*Quiscalus major*)
	Snyder and Snyder, 1969	Feeding by Limpkins (*Aramus guarauna*), Boat-tailed Grackles, and Snail Kites
	Kushlan, 1976a,b; 1978a; 1979b	Foraging ecology of wading birds
Mammals	Schwartz, 1952; Layne, 1984	Faunal composition/habitat relations
	Loveless, 1959b	White-tailed deer (*Odocoileus virginianus*) ecology
	Porter, 1953; Tilmant, 1975	Round-tailed muskrat (*Neofiber alleni*) ecology
	Smith, 1980	Everglades mink (*Mustela vison evergladei*) ecology
	Smith and Vrieze, 1979	Everglades rodent populations/ habitat relations

*Source: Gunderson and Loftus, in press.

Kushlan (1982b). Exemplary studies of wading birds include Kushlan (1976a, 1977, 1978a, 1979a, and 1979b) and Frederick and Collopy (1988). Other workers have studied the ecology of a single aquatic species, such as the Wood Stork (Ogden *et al.*, 1976; *op. cit.*, 1978).

Important works on reptile communities were done by Duellman and Schwartz (1958) and Dalrymple (in press). Ligas (1960) contributed to information on the biology of the pig frog (*Rana grylio*). Studies of the American alligator have been done by Craighead (1968), Kushlan (1974), Kushlan and Kushlan (1979), and Fogarty (1984).

Layne (1984) provided an excellent review of the mammals of southern Florida. Mammal species that have received special study include the Everglades mink (*Mustela vison evergladensis*) by Smith (1980), round-tailed muskrat (*Neofiber allenii struix*) by Porter (1953) and Tilmant (1975), and the white-tailed deer (*Odocoileus virginianum*) by Loveless (1959).

Zoogeographical Relationships. The fauna of the ENP Planning Area is comprised of a mixed taxa derived from temperate and tropical regions (primarily neotropics). A number of endemic and exotic taxa also are found in southern Florida and the ENP. Although such faunal mixing should result in a high diversity of species, authors of monographs on particular animal groups have repeatedly stated that each group is species poor in the Everglades (mammals-Layne, 1984; land birds-Robertson and Kushlan, 1984; reptiles and amphibians-Duellman and Schwartz, 1958). Only terrestrial insects appear to be the exception, although Dalrymple (in press) reports that the herpetofauna is not depauperate of species when compared to similarly sized areas.

The majority of animal species found in the area have colonized from temperate regions, primarily the southeastern coastal plain. All of the land mammals, and most of the breeding birds, reptiles and amphibians appear to have colonized from the coastal plain and Floridan peninsula (Layne, 1984; Gunderson and Loftus, in press). The wetland and wading bird species are distributed through the West Indies and the Everglades (Robertson and Kushlan, 1984). Endemism in southern Florida occurs at the subspecific level, generally as races or subspecies. Examples of endemic animals include the Everglades mink, the rice rat (*Oryzomys palustris coloratus*), the hispid cotton rat (*Sigmodon hispidus spadicipygus*), the round-tailed muskrat (Layne 1984) and the Cape Sable Seaside Sparrow (Werner, 1976).

The predominance of temperate species in the impoverished fauna of the Everglades may be explained in part by the physical setting, environmental conditions and its recent geologic age. The southern tip of Florida is a sub-tropical terminus of a moderately temperate peninsula. The area is separated from other tropical areas by large expanses of salt water, making dispersal from the tropics difficult for most non-flying animals including most mammals, reptiles, amphibians, and freshwater fishes. However, even the wading and land birds are less diverse than those in nearby tropical areas, such as Cuba (Robertson and Kushlan, 1984).

Environmental conditions in southern Florida may partially account for the impoverished faunal groups. Upland forested habitat is limited, therefore only limited numbers of terrestrial or arboreal animals may be supported. Aquatic habitats, although extensive, are not diverse and consist mainly of seasonally fluctuating marshes and swamps. While these aquatic systems once supported tremendous populations of birds and alligators, the relative homogeneity of the habitat did not result in a high diversity of species.

Faunal Groups

Reptiles and Amphibians. At least 44 species of amphibians and reptiles occur within the Everglades (Duellman and Schwartz, 1958; Dalrymple, in press). Most of the herpetofauna are reptiles (30 species), with snakes comprising the majority of the species (16 species: Dalrymple, in press). The other reptiles found in the park include 9 species of turtles and 5 species of lizards. Fourteen species of amphibians have been recorded (Duellman and Schwartz, 1958; Dalrymple, in press). Records for at least six species of exotic reptiles and amphibians also exist.

Birds. Robertson and Kushlan (1984) indicate that even though nearly 400 species of birds have been recorded in southern Florida, the regional avifauna is characterized by about 300 taxa. These authors relate that most of these species (60 percent) are wintering and migrant birds, and about 116 species comprise the native breeding avifauna. A checklist of the birds of ENP lists 347 taxa (Robertson *et al.* 1984). Toops and Dilley (1986) also provided a broad overview of bird life in southern Florida with emphasis on the Everglades. The heron (Ardeidae) and hawk (Accipitridae) families are the most speciose groups in the park (Gunderson and Loftus, in press).

Mammals. Schwartz (1952) and Layne (1984) listed the mammals that occur within the ENP. Layne (1984) stated as many as 30 species have been seen or collected. The most speciose group is the carnivores, whereas the most abundant group is the rodents (Layne, 1984). A noted feature of the mammal fauna is the near absence of bats (Layne, 1984).

Faunal Communities of Major Habitat Types The major habitat types found in the ENP Planning Area can be broadly grouped in the categories of upland forests, wetland forests, marshes, wet prairies, open water ponds and creeks, and mangrove forests. Few animals are restricted to a single habitat, and indeed, most animals occur in a variety of plant communities. The use of different habitats is linked in part to, and influenced by, the annual water level cycle. For example, as the freshwater marshes dry out, some primarily terrestrial animals will enter wetland habitats to forage. The animal occurrence and abundance information presented below attempts to describe the characteristic fauna of these broad habitat types. Summary lists of characteristic vertebrate fauna of major Everglades habitats are given in **Table 56.**

Table 56. Characteristic Avifauna, Herpetofauna, and Mammals of Major Everglades Habitats.

Species	Occurrence
HARDWOOD HAMMOCKS AND BAYHEADS	
Raccoon (*Procyon lotor*)	Resident, especially during high water
Opossum (*Didelphis marsupialis*)	Resident, especially at high water
Cotton mouse (*Peromyscus gossypinus*)	Resident
Hispid cotton rat (*Sigmodon hispidus*)	Resident
Marsh rabbit (*Sylvilagus palustris*)	Resident
White-tailed deer (*Odocoileus virginianus*)	Resident, especially at high water
Red-shouldered Hawk (*Buteo lineatus*)	Resident; important nesting site
Great Blue Heron (*Ardea herodias*)	Nests in bayheads
Barred Owl (*Strix varia*)	Resident; important nesting site
Blue-gray Gnatcatcher (*Polioptila caerulea*)	Winter resident
Various Warblers (Parulidae)	Migrants; some winter residents
Cardinal (*Richmondena cardinalis*)	Resident
Peninsula cooter (*Chrysemys floridana peninsularis*)	Uses edges for nesting
Red-bellied slider (*Chrysemys nelsonii*)	Uses edges for nesting
Everglades rat snake (*Elaphe obsolet rossalleni*)	Resident
Black racer (*Coluber constrictor*)	Resident
Florida kingsnake (*Lampropeltis getulus floridana*)	Resident
Southern leopard frog (*Rana sphenocephala*)	Breed along flooded edges
Southern toad (*Bufo terrestris*)	Breeds along flooded edges
SAWGRASS MARSHES	
Rice rat (*Oryzomys palustris*)	Resident
Cotton mouse (*Peromyscus gossypinus*)	More common in dry season
Hispid cotton rat (*Sigmodon hispidus*)	More common in dry season
Marsh rabbit (*Sylvilagus palustris*)	Resident
King Rail (*Rallus elegans*)	Resident
Limpkin (*Aramus guarauna*)	Seasonal resident
Red-winged Blackbird (*Agelaius phoeniceus*)	Resident; winter migrant
American Bittern (*Botaurus lentiginosus*)	Winter resident
Long-billed Marsh Wren (*Cistothorus palustris*)	Winter resident
Yellowthroat (*Geothlypis trichas*)	Resident
American alligator (*Alligator mississippiensis*)	Important nesting site
Squirrel tree frog (*Hyla squirella*)	Resident
Green anole (*Anolis carolinensis*)	Resident
WET PRAIRIES AND SLOUGHS	
White-tailed deer (*Odocoileus virginianus*)	Resident
Round-tailed muskrat (*Neofiber alleni*)	Resident
Everglades mink (*Mustela vison evergladensis*)	Resident
Otter (*Lutra canadensis*)	Resident
Hispid cotton rat (*Sigmodon hispidus*)	Resident
Cotton mouse (*Peromyscus gossypinus*)	Resident
Wading birds (*Egretta* spp., *Ardea, Casmerodius, Nycticorax*)	Important dry-season feeding areas
White Ibis (*Eudocimus albus*)	Feeds and breeds in shallow areas
Wood Stork (*Mycteria americana*)	Feeds in drying marshes
Common Moorhen (*Gallinula chloropus*)	Feeds and nests in marshes
Pied-Billed Grebe (*Podilymbus podiceps*)	Feeds and nests in winter
Belted Kingfisher (*Megaceryle alcyon*)	Winter resident
Boat-tailed Grackle (*Quiscalus major*)	Resident
Common Grackle (*Quiscalus quiscula*)	Winter resident
Limpkin (*Aramus guarauna*)	Resident
American alligator (*Alligator mississippiensis*)	Resident
Greater Siren (*Siren lacertina*)	Resident
Southern cricket frog (*Acris gryllus gryllus*)	Resident
Pig frog (*Rana grylio*)	Resident, usually near ponds
Water snakes (*Nerodia* spp.)	Resident
WET PRARIES (MARL)	
Striped crayfish snake (*Regina alleni*)	Resident
Black swamp snake (*Seminatrix pygmaea*)	Resident
White-tailed deer (*Odocoileus virginianus*)	Resident

Source: Gunderson and Loftus, in press

Table 56. Characteristic Avifauna, Herpetofauna, and Mammals of Major Everglades Habitats (Continued).

Species	Occurrence
WET PRARIES (MARL)--Continued	
Hispid cotton rat (*Sigmodon hispidus*)	Resident
Rice rat (*Oryzomys palustris*)	Resident
Marsh rabbit (*Sylvilagus palustris*)	Resident
Florida panther (*Felis concolor coryi*)	Resident
Least shrew (*Cryptotis parva*)	Resident
American Bittern (*Botaurus lentiginosus*)	Winter resident
Cattle Egret (*Bubulcus ibis*)	Resident
Great Egret (*Casmerodius albus*)	Feeds in flooded prairies
Red-shouldered Hawk (*Buteo lineatus*)	Resident
King Rail (*Rallus elegans*)	Resident
Common Nighthawk (*Chordeiles minor*)	Summer nester
Eastern Meadowlark (*Sturnella magna*)	Resident, common in dry season
Yellowthroat (*Geothlypis trichas*)	Resident
Cape Sable Seaside Sparrow (*Ammodromus maritimus*)	Resident
Green Anole (*Anolis carolinensis*)	Resident
Southern leopard frog (*Rana sphenocephala*)	Resident
Oak toad (*Bufo quercicus*)	Resident
Narrow-mouthed toad (*Gastrophryne carolinensis*)	Resident
PONDS AND CREEKS	
Round-tailed muskrat (*Neofiber alleni*)	Nests along margins
Rice rat (*Oryzomys palustris*)	Resident in marginal vegetation
Otter (*Lutra canadensis*)	Occasional
Wading birds (*Egretta* spp., *Mycteria, Casmerodius, Eudocimus*)	Feed along margins at low water
Black-crowned Night Heron (*Nycticorax nycticorax*)	Feeds and nests along pond edges
Anhinga (*Anhinga anhinga*)	Feeds & nests near ponds
Turkey Vulture (*Cathartes aura*)	Feeds along edges at low water
Purple Gallinule (*Porphyrula martinica*)	Feeds and nests in marginal vegetation
Boat-tailed Grackle (*Quiscalus major*)	Feeds and nests in marginal vegetation
American alligator (*Alligator mississippiensis*)	Digs and maintains ponds
Water snakes (*Nerodia* spp.)	Common at low water
Florida softshell (*Trionyx ferox*)	Resident
Two-toed amphiuma (*Amphiuma means*)	Resident
Pig frog (*Rana grylio*)	Resident, around edges
Southern leopard frog (*Rana sphenocephala*)	Resident, around edges
Peninsula newt (*Notophthalmus viridescens*)	Resident

a Information derived from: Layne, 1984; Robertson and Kushlan, 1984; Schwartz, 1952; Duellman and Schwartz, 1958; Loftus and Kushlan, 1987; Loftus *et al.* 1986, in press; Werner, 1976.

Source: Gunderson and Loftus, in press

Upland Habitats. The upland habitats are comprised of tropical hardwood hammocks and rockland pine forests. The tropical hammocks which are located in the wetland complex and saline zone probably have a less diverse fauna than the hammocks in the area of Long Pine Key. Most truly terrestrial animals are found in the upland habitats; most utilize both hammocks and pinelands, while a few are found exclusively in one or the other habitat. Most large mammals with large ranges, such as the black bear (*Ursus americanus floridanus*), white-tailed deer, and Florida panther (*Felis concolor coryi*) utilize both upland types.

Hammocks and their characteristically dense foliar cover provide unique habitat in southern Florida. Gene flow is restricted between these small, isolated, and disjunct areas, resulting in some unique examples of faunal diversity such as the color forms of the tree snail (*Liguus fasciatus*) (Pilsbry, 1946).

The most abundant mammals in tropical hammocks are the small rodents. One of the few quantitative studies of the fauna of hammocks was done by Smith and Vrieze (1979). They (*op. cit.*) studied population dynamics of the cotton mouse (*Peromyscus gossypinus*), hispid cotton rat, and rice rat, and found mean annual densities of 117, 27, and 19 individuals per hectare for the three rodent species, respectively. Other mammals that utilize hammocks include the shrews (*Blarina* sp.) and the gray squirrel (*Sciurus carolinensis*).

The hammocks are one of the many habitats used by the breeding land birds of the ENP. Robertson and Kushlan (1984) list hammocks as one of the habitats used by non-passerine birds such as the White-Crowned Pigeon (*Columba leucocephala*), four species of owls, Pileated Woodpecker (*Dryocopus pileatus*), and passerines such as the Cardinal (*Richmondena cardinalis*), Red-Eyed Vireo (*Vireo olivaceus*), Black-Whiskered Vireo (*Vireo altiloquus*), and northern Parula Warbler (*Parula americana*). The herpetofauna characterizing the hammock forests include various snakes such as the eastern Indigo snake (*Drymarchon corais couperi*) (Steiner *et al.*, 1983), several lizard species, and the southern Leopard frog (*Rana spenocephala*) (Dalrymple, in press).

The rockland pine forests of the ENP represents the last remnant of a once-extensive forest which covered the rock ridge from Miami south to the ENP. The open pine forests supported a faunal assemblage similar to pine flatwoods elsewhere in Florida, yet not quite as speciose. Common mammal residents include the white-tailed deer, bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), and opossum (*Didelphis marsupialis*). Less commonly found are the striped skunk (*Mephitis mephitis*) and gray fox (*Urocyon cineroargenteus*) (Layne, 1984). The avifauna of the pinelands is less diverse than other southeastern coastal or tropical pine types (Robertson and Kushlan, 1984), supporting 15 breeding species at an average density of 45 males per hectare. Robertson (1955) found the populations of Pine Warbler (*Dendroica pinus*), Red-Bellied Woodpecker (*Melanerpes carolinus*), Eastern Meadowlark (*Sturnella magna*), and Mockingbird (*Mimus polyglottus*) had the highest densities in the old-growth pine forest of Long Pine Key, while Bobwhite (*Colinus virginiana*), Red-Bellied Woodpeckers, Pine Warbler, Blue Jay (*Cyanocitta cristata*), and Loggerhead Shrike (*Lanius ludovicianus*) were the most abundant species in a younger pine forest. Dalrymple (in press) found the most common reptiles in the pinelands were the green anole (*Anolis caroliniensis*) and the black racer (*Coluber constrictor*); the southern toad (*Bufo terrestris*) and the exotic greenhouse frog (*Eleutherodactylus planirostis*) were the common amphibians.

<u>Wetland Forest Habitats</u>. The wetland forest habitat includes bayheads, swamp forests, cypress forests, willow heads, and pond apple forests. Most of these forests are relatively small and are generally surrounded by emergent marshes of low stature. These habitats, especially those forests surrounding alligator ponds, are notable as roosting and nesting sites for many wading birds and other marsh birds. Common breeding water birds found in these wetland forests include the Anhinga (*Anhinga anhinga*), Green-Backed Heron (*Butorides striatus*), Black-Crowned Night Heron (*Nycticorax nycticorax*), and the Boat-Tailed Grackle (*Quiscalus major*) (Sprangers, 1980; Robertson and Kushlan, 1984). In many of the tree islands of the park, tropical hammocks occur surrounded by wetland forests. Many of the birds listed above from hammocks also utilize these wetland forests. Common mammals include the ubiquitous raccoon and opossum; the river otter (*Lutra canadensis*) occurs around the wetter sites. Water snakes (*Nerodia* spp.), the green anole, and various turtles occur in these and other habitat types.

Marshes. The freshwater marshes, especially the open water marshes, ponds and sloughs, are extremely important habitats to wading birds and some mammals. Other marshes, such as the areally-dominant sawgrass marshes, have a dearth of animal life. The sawgrass marshes offer poor habitat because of high summer temperatures and a high density of emergent sawgrass culms. The only animals which utilize sawgrass marshes do so seasonally, such as the American Bittern (*Botaurus lentiginosa*), Long-Billed Marsh Wren (*Cistothorus palustris*), Limpkin (*Aramus guarauna*), and the American alligator (*Alligator mississippiensis*), which often constructs nests in these marshes (Craighead, 1968; Fogarty, 1984; Kushlan and Kushlan, 1980b). Resident mammals of the other marsh types include the river otter, the round-tailed muskrat, and various small rodents (Layne, 1984). Tilmant (1975) found muskrat densities of 50 to 205 houses per hectare.

Most of the wading and water birds of the Everglades utilize marsh habitats (generally excluding sawgrass marsh). The waders found in these habitats include the Wood Stork (*Mycteria americana*), White (*Eudocimus albus*) and Glossy (*Plegadis falcinellus*) Ibis, Great Blue Heron (*Ardea herodias*), Green-Backed Heron (*Butorides striatus*), Tri-Colored Heron (*Hydranassas tricolor*), Black-Crowned Night Heron (*Nycticorax nycticorax*), Great Egret (*Casmerodius albus*), Snowy Egret (*Egretta thula*), Least Bittern (*Ixobrychus exilis*), and American Bittern. The White Ibis was historically and remains the most abundant wading bird in southern Florida. Densities of these birds vary seasonally. Kushlan and Kushlan (1977) counted 96 birds per square kilometer (km^2) during the spring and summer months and found more than 379 birds/km^2 during the winter (Kushlan and Kushlan, 1976).

Other animals which comprise the fauna of the wetland marshes include the Snail Kite (*Rostrhamus sociabilis*), American alligators, pig frog, cricket frog (*Acris grylio*), water snakes, peninsular newt, and several sirens (Gunderson and Loftus, in press).

Wet Prairies. Wetland prairies are seasonally inundated freshwater marshes with marl or mud substrates. They occur in areas with shorter hydroperiods than marshes. These prairies have relatively high variation in local topography. Potholes from 0.5 to 1.0 meter deep, created by dissolution of the soft limestone, form aquatic habitats within the higher and drier wetland prairies. These solution holes are important dry season refugia for aquatic species (Loftus and Kushlan, 1987; Dalrymple, in press).

Wet prairies support a diverse herpetofauna. Duellman and Schwartz (1958) found 46 species in these habitats. The green anole, southern Leopard frog, and oak toad (*Bufo quericus*) were the most common reptiles found in these prairies (Dalrymple, in press). These areas also are the first marshes to dry out, and consequently, offer the first feeding areas for wading birds. Much of the remnant functional wet prairie in southern Florida is in ENP, and is designated as critical habitat for the Cape Sable Seaside Sparrow. Of all habitats found in the original Everglades ecosystem, the wetland prairie has experienced the most significant losses or alterations by urban or agricultural development. Prairie habitat in the East Everglades area outside of ENP is being considered for inclusion into the park in recognition of its importance to park wildlife.

Ponds and Creeks. Ponds and creeks are habitats that remain wet during all but the driest years. Usually, ponds are created and maintained by the activity of the American alligator (Craighead, 1968; Kushlan, 1974). Creeks are ecologically analogous to ponds, but are located at the landward side of the rivers that empty into the Gulf of Mexico and Florida Bay. Large salamanders, turtles, and snakes also inhabit these aquatic habitats. Common mammals include the river otter and round-tailed muskrat. Birds that feed in these ponds are affected by the water depth in gaining access to food. During periods of high water, water birds such as the Common Moorhen (*Gallinula chloropus*), Pied-Billed Grebe (*Podilymbus podiceps*), Anhinga (*Anhinga anhinga*), and Limpkin may be common. Vultures, wading birds and more-terrestrial fauna are commonly observed using these sites during dry periods. These deep-water habitats are critical to dry-season survival of many aquatic species.

Mangrove Forests and Coastal Prairies. Mangrove forests often surround open, gramineous wetlands (coastal prairies) in the saline zone of the park. These forests provide important habitats to many animals, including several rare and endangered taxa. Common mammals in the mangroves include the raccoon and bobcat. Layne (1984) reviewed the sitings of bobcats in the park and found that a high incidence occurred in the mangrove zone. Although found in mangrove habitats, the mangrove or Everglades fox squirrel (*Sciurus niger avicennia*), also occurs in cypress and pineland sites (Layne, 1984). The rare manatee (*Trichechus manatus latirostris*) also occurs in the mangrove lined waters of the ENP. Historical rookeries in the mangroves once held tens of thousands of birds (Robertson and Kushlan, 1984; Ogden *et al.*, 1987). Other birds more closely associated with mangroves include raptors such as the Southern Bald Eagle (*Haliaeetus leucocephalus leucocephalus*) (Nesbitt *et al.*, 1975) and Prairie Warbler (*Dendroica discolor*) (Toops and Dilley, 1986).

The herpetofauna of the mangrove zone includes common species such as the tree frogs and anoles as well as rare species such as the American crocodile (Mazzotti *et al.*, 1988), mangrove water snake (*Nerodia sipedon compressicauda*), and mangrove terrapin (*Malaclemys terrapin rhizophorarum*).

Factors Affecting the Faunal Communities. Both abiotic and biotic factors affect the composition, abundance, and distribution of the animals within ENP. These factors vary both spatially and temporally, resulting in a complex, ever changing set of conditions to which the fauna must adapt. The dominant abiotic forces which shape the communities include the annual patterns of rainfall and water levels, recurrent cyclonic storms, fires, and occasional frosts and freezes. Biotic influences of competition, commensalism, and predation configure the communities as well, but less study has been devoted to the biotic factors compared to information on the abiotic forces.

Abiotic Factors. The annual rainfall pattern of wet summer and dry winter seasons is one of the most dramatic influences on all groups of animals, and is a major factor which structures most of the wetland faunal assemblages. Typically, most (85 percent) of the rain occurs during the months of June through October, with the remainder falling throughout the fall, winter, and spring months. Since the Everglades is primarily a rainfall-driven hydrologic system, water levels follow the annual rainfall pattern. Peak annual depths occur at the end of the wet summer season during October and November. Dry season rainfall amounts determine the rate of water level recession. Water levels generally continue to decline during the winter and early spring, reaching annual minimum depths during April and May. Animals of the Everglades are adapted to various aspects of the hydrology, with key parameters being the rate of recession (Ogden *et al.*, 1976; Robertson and Kushlan, 1984) and the depth of water during spring months.

Flooding of the marshes during the summer months initiates aquatic production, as macrophytes and algae photosynthetically fix carbon, which in turn is consumed by fish and invertebrates. Fish and invertebrates are major dietary components of the wading and water birds. High water levels also restrict terrestrial animals to upland habitats. One such example is the white-tailed deer, which is restricted to hammocks and pinelands during extreme rainfall and flood events. The wet summer season also creates appropriate conditions to support large populations of invertebrates, especially mosquitoes.

Most of the ecological work on wading birds has investigated the influence of the dry season on populations, especially feeding distribution (D. M. Fleming, unpublished data) and nesting success (Frederick and Collopy, 1988; Kushlan, 1987; Ogden *et al.*, 1978). The dry season is correlated with the period of nesting of most inland wading birds (Robertson and Kushlan, 1984). As water levels decline, fish and invertebrates are concentrated within depressions in the marshes. Fish densities of 500 animals per square meter are not unusual at such locations (Loftus *et al.* in press), making the food readily available to avian, reptile and piscine predators and scavengers. Robertson (1964), Robertson and Kushlan (1984), and Ogden *et al.* (1978) link the success of the Wood Stork to the hydrologic status during the spring. In many years when surface water levels are high, wading birds experience poor nesting results. Although waders benefit from spring drawdowns, other avian species, such as Limpkins, Pied-Billed Grebes, and Snail Kites (Bennetts *et al.*, 1988) increase populations when water levels remain high.

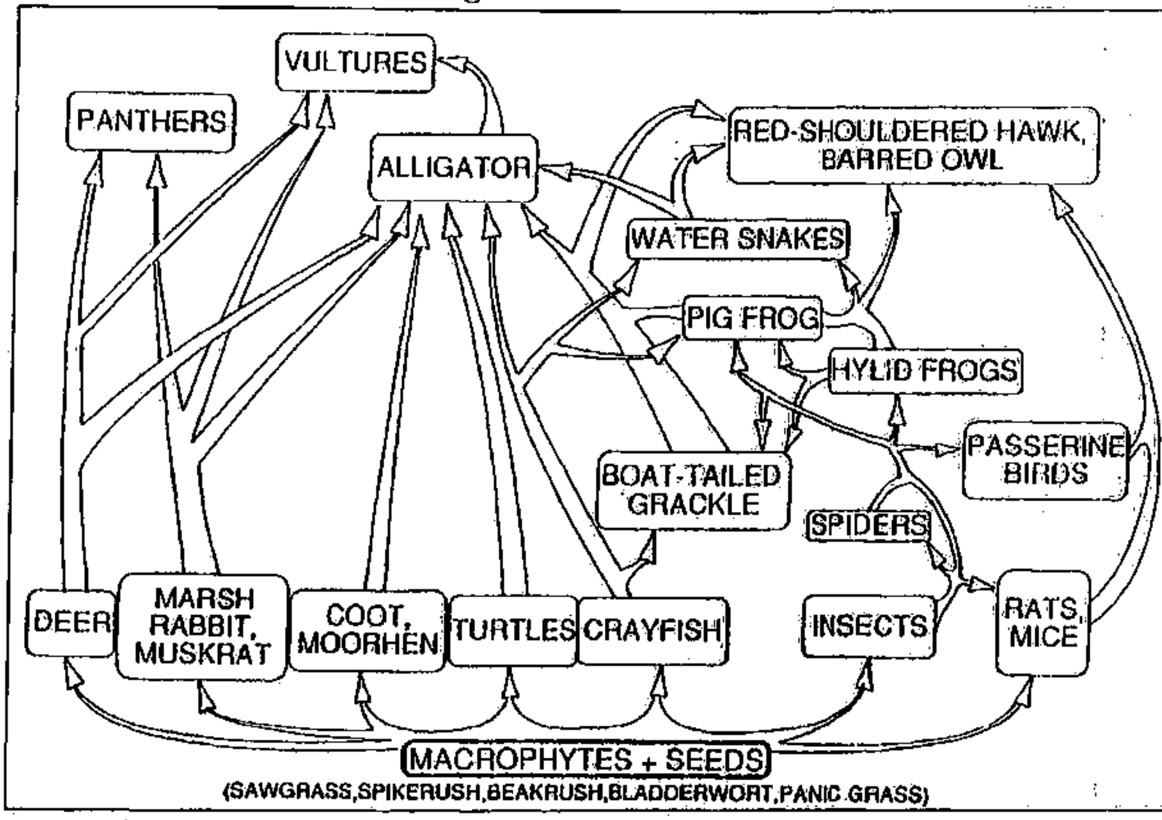
Fire is a recurrent natural disturbance in most habitats (except mangroves) in the planning area. Fires can cause direct mortality; reptiles and rodents have been reportedly consumed by fires (Robertson, 1955; Wade *et al.*, 1980). Robertson and Kushlan (1984) thought that nesting ground birds may also be consumed by fires. Most of the influences on birds and other animals are linked to habitat modification. Robertson (1955) found that ranges of forest and edge bird species may change if forest margins are consumed by fire.

Cold, often freezing, temperatures that occur following the passage of winter cold fronts seldom have direct effects on the fauna, but rather may have slight, indirect effects. The frosts defoliate sensitive tropical vegetation and often kill some insects. Populations of insectivorous birds may drop following such an incident (Robertson and Kushlan, 1984).

Hurricanes have caused locally heavy mortality of nesting and roosting birds found in coastal areas (Robertson and Muller, 1961). Effects on mammals and herpetofauna are poorly understood, but may be temporarily significant.

Biotic Factors and Trophic Interactions. Biotic factors which influence the fauna are primarily related to consumption or predation, and to effects associated with activity of certain key species. Predation is one of the processes by which energy flows through the ecosystem. Primary production occurs in the herbaceous macrophytes and periphyton of the wetland areas (Browder *et al.*, 1981, 1982), with little or no contribution by phytplankton (Van Meter, 1965). In freshwater marshes, upland vegetation complexes, and mangrove systems, detritally-based food webs appear most important (Odum, 1971; Gunderson and Loftus, in press; Loftus *et al.*, in press). Odum (1971) related the importance of mangrove detritus to secondary production of estuarine systems in the park. Gunderson and Loftus (in press) present generalized food webs supported by the grazing pathway (**Figure 48**) and detrital pathway (**Figure 49**) for freshwater wetland systems.

Figure 48. General Macrophyte-Based Trophic Relationships Among Characteristic Everglades Animals.



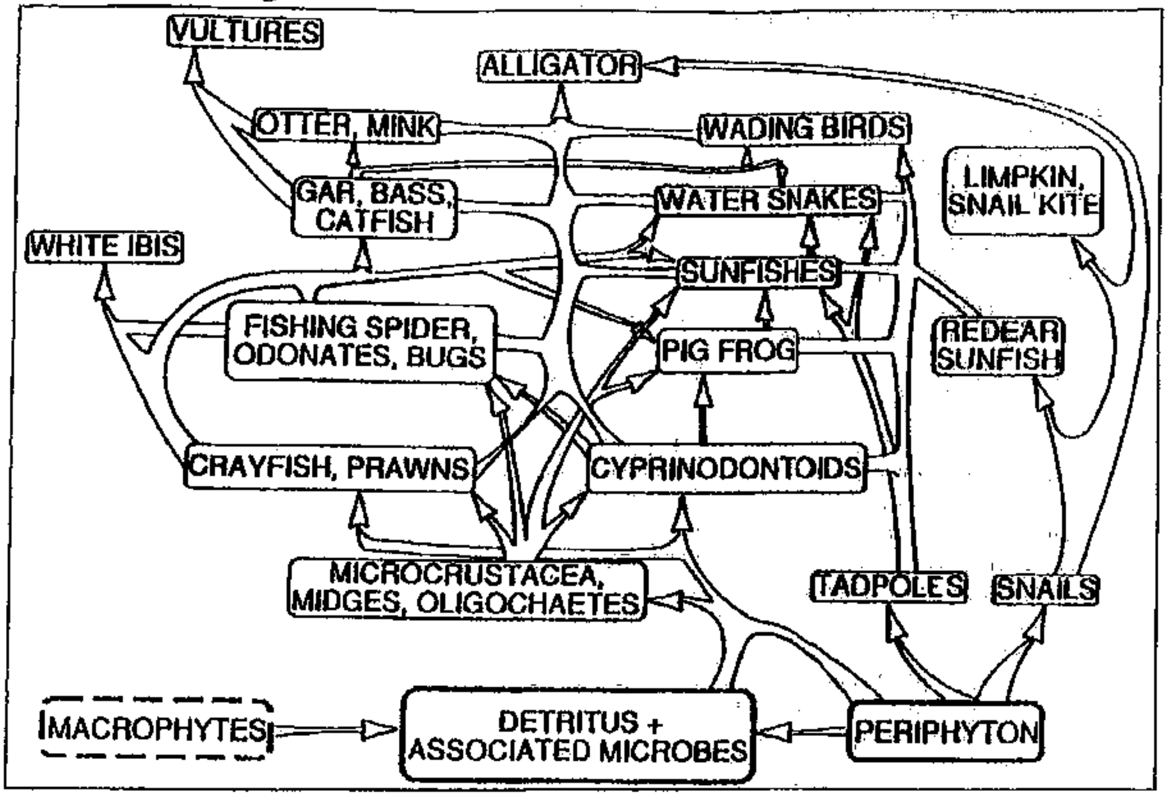
Source: Gunderson and Loftus, in press

Some animals may occupy various trophic levels, depending upon their stage in life. Some species, such as the Limpkin and Snail Kite, are specialists. Both of these birds feed on the apple snail, *Pomacea paludosa* (Snyder and Snyder, 1969). Other speicies, such as the alligator are generalists that consume a variety of animals (Fogarty, 1984). The influence of the alligator on the Everglades ecosystem has received much study (Craighead, 1968; Kushlan, 1974; Fogarty 1984). Alligators keep ponds and creeks free from accumulation of vegetation and organic soil, thereby offering a dry season refuge for aquatic organisms. Alligator nests may also provide nuclei for establishment of tree islands (Craighead, 1968), and dry nest sites for turtles and anoles (Kushlan and Kushlan, 1980a).

Introduced and Exotic Fauna. Most of the introduced and exotic fauna which occur in the planning area can be traced to intentional importation primarily for the pet trade, while others are animals adapted to the conditions humans create in conjunction with urban and agricultural development. Several species were introduced for food and sporting purposes or to control pest species. Although present, few of the alien taxa are abundant in the ENP itself.

The exotic mammals in the ENP range in size from the wild hog (*Sus scrofa*) to the house mouse (*Mus muscalus*). Other mammals reported in the ENP are the nine banded armadillo (*Dasypus novemcinctus*), red fox (*Vulpes vulpes*), and the jaguarundi (*Felis yagouaroundi*) (Layne, 1984). Accounts of unusual animals from the ENP include a spider monkey (*Atelis* sp.) (Layne 1984) and a coatimundi (*Nasua narica*) (Loftus, personal communication)

Figure 49. General Detritus-Based Trophic Relationships Among Characteristic Everglades Animals.



Source: Gunderson and Loftus, in press

Most of the established exotic birds of southern Florida nest in the developed and suburban areas. These birds have been released and take advantage of under-utilized niches (Robertson and Kushlan, 1984). Some of these find their way into the ENP, although few if any nest there. Common exotics include five species of parrots, Red-Whiskered Bulbul (*Pycnonotus jocosus*), Hill Myna (*Gracula religiosa*), Blue-Gray Tanager (*Thraupis episcopus*), and Java Sparrow (*Padda oryzivora*), Starling (*Sturnus vulgaris*), and House Sparrow (Robertson and Kushlan, 1984). The Collared Dove has recently been sighted in the ENP.

The exotic herpetofauna of southern Florida are primarily small lizards and frogs. The lizards include five types of geckos, and five types of anoles. Common frogs include the Cuban tree frog (*Hyla septentrionalis*) and the marine toad (*Bufo marinus*). Caimans (*Caiman crocodylus*) have been found nesting near canals on the boundaries of the ENP (Discussion December, 1989 with William Loftus, SFRC).

Threatened and Endangered Species and Species of Special Concern. Populations of some animal species have experienced tremendous declines in south Florida. Factors that have led to decreased populations include the loss of habitat (as areas are developed for urban and agricultural use), intensive harvest and over harvesting, altered hydroperiods, and alteration of fire patterns. Some marsh animal populations have been jeopardized by certain water management actions that affected aspects of their life histories.

Ten species of southern Florida animals have been designated as threatened or endangered by the U.S. Fish and Wildlife Service (**Table 57**). The Florida Game and

Table 57. Endangered and Threatened Animals which Utilize Everglades Habitats, with Notes on their Regulatory Status.

Taxa	Preferred Habitat	Status*
MAMMALS		
Florida Panther, *Felis concolor coryi*	Cypress, Mangrove, Pine Forest	E (F), E (S)
Mangrove Fox Squirrel *Sciurus niger avicennia*	Hammock; Pine and Cypress Forest	E (S)
Florida Black Bear *Ursus americanus floridanus*	Hammock; Bayhead; Pine; Mangrove Forests, Cypress	T (S)
Everglades Mink *Mustela vison evergladensis*	Cypress and Mangrove Forests; Wet Prairies	T (S)
Manatee. *Trichechus manatus latirostris*	Saltwater Bays; Estuaries	E (F), E (S)
BIRDS		
Wood Stork, *Mycteria americana*	Freshwater and Brackish Marshes; Ditches, Depressions; Cypress and Mangrove Forest	E (F), E (S)
Snail Kite, *Rostrhamus sociabilis plumbeus*	Freshwater Sloughs and Wet Prairies; Sawgrass Marshes	E (F), E(S)
Cape Sable Seaside Sparrow, *Ammospiza maritima mirabilis*	Freshwater and Brackish Marshes	E (F), E (S)
Peregrine Falcon, *Falco peregrinus anatum*	Mangrove Forests; Ponds and Sloughs	E (F),E (S)
Southern Bald Eagle, *Haliaeetus leucocephalus leucocephalus*	Freshwater Marshes; Cypress and Mangrove Forests	E (F),T (S)
Brown Pelican, *Pelecanus occidentalis caroliniensis*	Mangrove Forest; Estuaries	T (S)
REPTILES		
American alligator, *Alligator mississippiensis*	Freshwater Marshes; Cypress Forest	T (F)
Eastern Indigo Snake, *Drymarchon corais couperi*	Hammocks; Pine Forest	T (F),T (S)
American crocodile, *Crocodylus acutus*	Mangrove Forest; Brackish Bays and Creeks; Ponds and Canals	E(F),E (S)

Source: Gunderson and Loftus, 1989; Layne (1976, 1984), McDiarmid (1978); Kale (1978).
*Status: E = Endangered, T = threatened, F = Federal (U.S. Fish and Wildlife Service), S = State (Florida Game and Freshwater Fish Commission)

Freshwater Fish Commission also lists threatened or endangered taxa which occur in the planning area (**Table 57**).

Mammals on the State list include the Florida panther, mangrove fox squirrel, black bear, Everglades mink, and manatee. Only the panther and manatee are federally listed. Birds which are listed as endangered by the federal government include the Wood Stork, Everglades Kite, Cape Sable Sparrow, Peregrine Falcon (*Falco peregrinus*), and southern Bald Eagle. The Florida Game and Freshwater Fish Commission adds the Sandhill Crane (*Grus canadensis*), Crested Caracara (*Polyborus plancus*), White-Crowned Pigeon, and southeastern American Kestrel (*Falco sparverius paulus*) to the list. Reptiles that occur on both lists are the eastern Indigo snake and American crocodile. The American alligator is listed as threatened by the federal government, but has been delisted by the State, which recently held a hunting season to allow harvest of surplus alligators. The Florida Committee on Rare and Endangered Plants and Animals (FCREPA) lists additional animals not on official state or federal lists. Accounts of selected key species and groups which are directly affected by water management policies are discussed below.

A few taxa are recently extirpated. Early naturalists found a number of mammals and birds which no longer are present in southern Florida. Layne (1984) lists the Florida red wolf (*Canis rufus floridanus*) as occurring in the state until the late 1800's. Birds present at the turn of the century, but no longer occurring in the area include the Carolina Parakeet and Red-Cockaded Woodpecker.

Wading Birds. Robertson and Kushlan (1984) present data to document the dramatic decline in the number of wading birds found in the interior wetlands of the Everglades. They estimated total populations numbered as high as 2.5 million birds in 1870, but then declined to 500,000 in 1910 as a result of plume hunting. Populations increased to 1.2 million birds by 1935 when hunting ceased. Since that time, total populations have declined to levels which are about 10 percent of the levels during the 1930s (Collopy and Frederick, 1986). The most recent decline has been attributed to loss of suitable habitat to drainage and development.

The most abundant wading bird historically and currently is the White Ibis, with population counts in the 1930's of 660,000 individuals (Robertson and Kushlan, 1984). Current levels vary a great deal about a mean of approximately 60,000 birds. Other birds which have declined in population are the egrets, small herons, and the Wood Stork. Total mainland breeding populations have been very low during the 1980's (Collopy and Frederick, 1986; Frederick and Collopy, 1987). Annual numbers of nesting great egrets has been less than 2,000 pairs, snowy egrets less than 1,500 pairs, and white ibis less than 2,500 pairs (Ogden *et al.*, 1987a). The primary nesting colonies of small herons, egrets, and White Ibis were located at the headwaters of Shark, Broad, and Lostmans Rivers in the ENP (Ogden *et al.*, 1987). The freshwater marshes adjacent to the mangroves between Lostmans and Shark River were historically the major feeding area for wading birds during the nesting season (Allen, 1958).

Wood Stork. The status of the Wood Stork is of particular concern in the ENP, perhaps because no other species is as good an indicator of the viability of the freshwater marshes. Historical populations of the stork in the ENP have declined precipitously. Reductions of about 20 percent occurred between 1930 and 1950. The decline was about 80 percent between 1960 and 1980 (Ogden *et al.*, 1987). Annual numbers of storks averaged about 2,000 pairs until 1960, although much variation occurred (Robertson and Kushlan 1984, Ogden and Patty, 1982, Ogden *et al.*, 1987). Coincident with the completion of the water management structures which deliver water to the ENP, numbers declined through the 1970's and 1980's. The mean annual breeding population of storks within the ENP was 374 pairs, with a range from 15 to 1,660 (Ogden *et al.*, 1987).

Since the wood stork is a tactile feeder, it is dependent upon fish concentrations to provide a reliable food base. The time of food availability and correlation with nesting success has been studied by Ogden *et al.* (1976), Browder (1976), and Kushlan and Frohring (1986). Ogden *et al.* (1987) argue that the decline of ENP populations is a result of alterations to the hydrology since 1960. They state that the scheduled water deliveries resulted in delayed and incomplete dry season drawdowns, which delayed nesting to the point that the nesting period extended into the wet season and the adults could no longer supply sufficient food for their young. Water management actions also led to flood releases in the dry season which reversed the recession of water levels and dispersed prey concentrations. Another major factor in the Wood

Stork population decline is believed to be the loss of peripheral wetlands, such as Northeast Shark Slough and its margins, which provided important early dry season feeding habitats.

Cape Sable Seaside Sparrow. The Cape Sable Seaside Sparrow is a subspecies of the Seaside Sparrow, first discovered in the coastal prairies near Ochopee, Florida, and near Cape Sable (Werner, 1976). The habitat and biology of the bird were studied by Werner (1976), Taylor (1983), and Werner and Woolfenden (1983). Currently it inhabits the peripheral wetland prairies which border Shark River Slough, Taylor Slough, and the rocky gladelands (Bass and Kushlan, 1982a). These populations appear stable, and are estimated at 6,600 birds (Bass and Kushlan, 1982a).

Snail Kites. Populations of this Everglades-dependent raptor have fluctuated greatly since the species was first discovered in Florida (Bennetts *et al.*, 1988). They (*op. cit.*) estimate that the number of kites in Florida ranged from 100 to more than a thousand individuals in the 1930's, declined to less than 100 in the mid-1900's, and increased to at least 668 birds by 1984. The decline in kites during the mid-1900's is attributed to drainage of marsh habitats. The recent increase is thought to be related to the impoundment of water in Water Conservation Area 3A since 1962. This conservation area has since become increasingly important to the Florida Snail Kite population (Bennetts *et al.*, 1988).

Today, the Snail Kite population undergoes wide fluctuations, corresponding to periods of drought or flooding (Beissinger and Takekawa, 1983; Sykes, 1983; Bennetts *et al.*, 1988). During the wet period from 1981 to 1985, Snail Kite numbers in northern Everglades National Park increased markedly, only to decline after the 1985 drought. The fluctuations seem to be partly in response to the availability and abundance of its exclusive prey, the apple snail.

Crocodilians. The American crocodile (*Crocodylus acutus*) occurs in southern Florida in coastal habitats such as mangrove swamps, salt and brackish water bays, and brackish creeks (Behler, 1978). The primary nest sites in Florida Bay are in the edge of hardwood thickets at the heads of small sand beaches or on relatively high marl banks of narrow coastal creeks (Ogden, 1978a). The crocodile is the dominant carnivore in these habitats and is presumed to play an important role in nutrient cycling and ecosystem dynamics (Behler, 1978).

Past exploitation and habitat loss have resulted in a decline in numbers of crocodiles. Data presented in Behler (1978) and Ogden (1978b) indicate that, as of 1978, only 100 to 400 individuals inhabited south Florida waters, of which only 20 to 25 were breeding females. One indirect effect of past drainage has been the alteration of salinity gradients within the former habitat of the crocodile, exposing hatchlings to high salinity conditions during the hatching season (Evans and Ellis, 1977). Other adverse influences on the crocodile population besides habitat loss, commercial exploitation, and drainage effects include possibly increased nest predation by raccoons (Ogden, 1978a; Behler, 1978), prolonged droughts, exotic plant species introductions and commercial fishing in nesting areas (Ogden, 1978a). Egg mortality due to desiccation and nest flooding was evaluated by Mazzotti *et al.* (1988).

The crocodile is currently listed as endangered on both Federal and State levels. Ogden (1978a) believed the population of crocodiles in Florida Bay could remain stable, provided that proper protection and habitat management measures continued to be taken.

Water management impacts on the American alligator have been demonstrated by Kushlan (1987), who correlated dry-season flood releases with alligator nest flooding and resultant egg mortality. Drainage of marshes, such as those in Northeast Shark Slough and East Everglades, appears to result in reduced carrying capacity for alligators (Fleming, in prep.). Lower densities of alligators in degraded marshes has an impact on other aquatic species because the dry-season refugia that the alligators create are less available.

9. Biological Resource Management and Ecological Relationships

Current Wildlife Management Problems. Over the past several decades, development and operation of the regional flood control system has altered the natural flow of waters to the planning area. Concurrently, land along much of the eastern boundary of the planning area has been cleared and drained to allow agricultural activity and residential development.

These practices have measurably affected the extent and condition of upland and wetland habitats needed for continued maintenance of natural wildlife species populations, and have contributed to the current distributions of both non-native species and some species of special concern. Hence, wildlife-related management problems for the planning area generally fall into the categories of water management, land uses, and critical species management.

Water Management. Water management concerns generally have been addressed in terms of either water quantity, distribution and timing or in terms of water quality issues. In reality, the effects of water management practices should not address either category individually; these aspects are integrally related. Assessment of the effects of water management practices on wildlife resources of the planning area should recognize this linkage.

Degraded water quality has been awarded the primary responsibility for changes in wetland vegetation observed in the water conservation areas to the north of the ENP Planning Area (Davis 1991; Swift and Nichols, 1987). Although specific effects of the referenced vegetation changes on wildlife have not been documented, it is generally presumed that altered marsh plant communities would have altered wildlife habitat value. Objective evaluation of relative values of altered habitats is needed prior to presuming a change is negative or positive.

The effects of altered deliveries of water may be either subtle or dramatic (Kolipinski and Higer, 1969), and impacts may occur under conditions of either too much or too little water. Excessively high water levels maintained for an extended period may drown tree islands (Worth, 1988), which are valuable habitats for terrestrial and arboreal wildlife species. Diversion of waters away from a wetland can also degrade marsh habitats ultimately reducing carrying capacity for vertebrates (Loftus, *et al.*, in press). As noted in prior sections, the timing of water deliveries is equally important. Unseasonal water releases may disrupt normal feeding behavior (e.g., wading birds) or breeding success (e.g., alligator nesting) of many of the planning area's key wildlife species (Kushlan, 1987).

Physical structures associated with water management (canals, levees, gates, and pumps) directly affect wildlife in a number of ways. For example, canals provide routes of rapid dispersal for exotic plant and animal species, potentially leading to more rapid invasion of natural habitats. Exotic species disrupt natural community integrity. Additionally, canal systems or related structures may inadvertently divert animals away from natural habitats, and in some cases, can be significant physical barriers to normal movements or activities (Loftus and Kushlan, 1987).

Land Uses. Land clearing activities associated with either agricultural or residential site development eliminates natural habitats. Development of short hydroperiod Everglades marshes in the East Everglades and associated basins has been implicated in wildlife declines (Ogden *et al.*, 1987; Kushlan, 1987). Prior to development, some of these areas afforded important early season foraging grounds for mammals, including the Florida panther.

Land development and associated habitat physical disturbances often provide opportunities for exotic organisms to invade adjacent natural systems. Indeed, humans are responsible for introducing several exotic species, and the resulting impacts on native communities (Loftus, in press; Wilson and Porras, 1983).

The expanding human population in South Florida places increasing pressures on Everglades wildlife in the forms of competition for limited water supplies, poaching, traffic- and boating related mortality, and noise disturbances. Fire suppression in and around developed areas allows habitat succession displacing some species and favoring non-native species (Hofstetter and Parsons, 1976, 1979; Wade *et al.*, 1980).

Critical Species Management. Critical species management efforts can be considered to include both restriction of exotic or non-native species distributions, and enhancement or restoration of populations of threatened and endangered species (or others of special concern). Generally, wildlife management efforts may be best approached through habitat management. For example, restoration of more natural hydroperiods through water management activities will favor reestablishment of vegetative communities conducive to increased habitat use by wading birds for foraging or breeding purposes (Frederick and Collopy, 1988).

Protection of natural habitats from invasion by exotic vegetation will also enhance planning area integrity for use by natural wildlife populations. In this sense, management of exotic species is a critical, although indirect, component of wildlife management efforts.

Wildlife Management Objectives. It should be recognized that the natural habitats of the planning area are extremely complex and integrated systems. Wildlife management objectives for the planning area will be equally complex. Management objectives directed at correcting one problem may ultimately have to be compromised with those directed at other issues. For example, restoration of more natural hydroperiods in the ENP and East Everglades will require modification of water delivery through Water Conservation Area 3. Such modifications may impact Snail Kite populations which have expanded into WCA-3 because of the deeper waters currently present (Bennetts *et al.*, 1988).

Hence, management actions which may ultimately preserve or protect habitats having value to a host of wildlife species may at times have to be weighed against potential negative effects on selected species of special concern. Management of wildlife issues in the planning area will require general consensus rather than unanimous agreement. Input from and cooperation between all concerned interests will be necessary to achieve results having long-term potential for improved preservation and enhancement of area wide wildlife resources. Management efforts for the Everglades should emphasize systemwide preservation and restoration rather than individual species management.

Aquatic Communities.

Historical Overview. Of the three major groups of organisms (microflora, invertebrates, and fishes), the largest body of literature has been written about the fishes, in particular the estuarine species. **Table 58** provides an overview of major studies of Everglades aquatic communities. Much of the work on estuarine fishes was done by research scientists associated with the University of Miami, School of Marine Sciences during the 1960's to early 1970's. Their pioneering studies in the ENP's estuary have been supplemented in recent years by research studies by staff and contractors of the South Florida Research Center. Freshwater fishes received the attention of these two organizations from the mid-1970's to present (**Table 58**).

Aquatic and estuarine invertebrates have not been studied to the degree of the fishes. Basic inventories have been made or are in progress, but much less is known about ecological relationships of these important taxa. The knowledge of periphyton, other algal associations, and submerged vegetation is similarly incomplete, with the inventories having been done, but their ecology still poorly understood.

Fishes. General treatments of the freshwater and estuarine Everglades regional ecology include those prepared by Tabb (1963), Odum *et al.* (1982), Schomer and Drew (1982), Wade *et al.* (1980), Durako *et al.* (1985), and Lewis *et al.* (1985). The treatment of tidal freshwater habitats by Odum *et al.* (1984), while not covering this geographical region, is applicable.

Early investigations of the fishes of southern Florida (Evermann and Kendall, 1900; Fowler, 1945; Carr and Goin, 1955; Briggs, 1958) included minor accounts of the ichthyofauna of the ENP area. Distributions of freshwater fishes in southern Florida were first described by Kilby and Caldwell (1955), Kushlan and Lodge (1974), and Dineen (1974). The most extensive sampling and distribution records within the ENP Planning Area are presented by Loftus and Kushlan (1987). Other studies included work on food habits by Hunt (1953) and Odum (1971), and on sunfish spawning by Clugston (1966). Ecological studies in the freshwater marshes include those by Tabb (1963), Kolipinski and Higer (1969), Kushlan (1976b, 1980), and most recently by Loftus (1988), and Loftus *et al.* (in press). Other workers (Ogden *et al.*, 1976; Kushlan, 1976a, 1979) discussed the role of freshwater fishes in the ecology of wading birds (**Table 58**).

Important works on estuarine fishes and invertebrates include the works of Davis and Williams (1950) and Tabb and his co-workers (Tabb and Manning, 1961; Tabb *et al.*, 1962, 1967, 1974; Tabb, 1963, 1966). These works described the composition of the fauna, provided a base for ecological understanding, and addressed the difficult issue of freshwater needs for the estuary. In the late 1960's to the early 1970's, the studies of estuarine fish populations by Odum (1971), Clark (1971), Roessler (1968), and Jannke (1971) led to increased understanding of fish movements, seasonality, and recruitment patterns. Odum (1971), Odum and Heald (1972), Heald (1971), and Heald *et al.* (1974) described the basic trophic inter-relationships in the Everglades estuary and demonstrated the important role of mangroves in detritus food webs. More recently, works by Rutherford *et al.* (1982, 1983, 1986), Thue *et al.* (1982), and Thayer *et al.* (1987) have focused on the life histories of important game fishes and forage species, and described fish distributions and abundances by habitat.

Table 58. Major Studies of Everglades Aquatic Communities

Research Topic	References
SUBMERGED FLORA	
Taxonomic composition, association with Utricularia	Brock, 1970; Browder, 1981, 1982; Swift, 1984; Swift and Nicholas, 1987; Van Meter, 1965, 1973; Wilson, 1974; Wood and Maynard, 1974.
Primary productivity, oxygen production, and stock biomass	Brock, 1970; Browder, 1981, 1982; Hunt, 1961; Swift, 1984; Swift and Nicholas, 1987; Van Meter, 1965, 1973; Wilson, 1974; Wood and Maynard, 1974.
Influence of hydroperiod and water chemical composition of periphyton	Swift, 1984; Swift and Nicholas, 1987; Flora *et al.* 1987; Hall and Rice, 1989 (unpublished data)
Deposition of calcitic muds by periphyton	Gleason, 1972; Gleason and Spackman, 1974.
Role of periphyton in food webs	Hunt, 1953; Browder et al., 1982.
Summary of information on root/mud algae and submerged vascular flora associated with mangroves	Odum et al., 1982.
INVERTEBRATES--FRESHWATER	
Population fluctuations of apple snails, Pomacea paludosa	Kushlan, 1975.
Relation of crayfish population (Procambarus alleni) to water level changes	Kushlan and Kushlan, 1979.
Hydrological relationships of the prawn, Palaemonetes paludosus	Kushlan and Kushlan, 1980.
Effects of hydroperiod on macro- and micro-invertebrate populations; community composition	Loftus et al., 1986 (in prep).
INVERTEBRATES--ESTUARINE	
Zooplankton and invertebrate communities and factors affecting organism distribution and density in estuarine waters	Davis and Williams, 1950; Tabb and Manning, 1961; Tabb et al., 1962; McPherson, 1970; Odum, 1971
Benthic and epibenthic invertebrate communities and ecological factors affecting them	Tabb and Manning, 1961; Tabb et al., 1962; Odum, 1971; Odum et al., 1982
Food habits and trophic interrelationships	Odum, 1971; Odum and Heald, 1972; Odum et al., 1982.
FISHES--FRESHWATER	
Forage for wading birds	Ogden et al., 1976; Kushlan et al., 1975.
Composition, distribution, and ecology	Kushlan and Lodge, 1974; Loftus and Kushlan, 1987; Dineen, 1974; Crowder, 1974.
Hydroperiod effects on density and biomass.	Reark, 1961, 1967; Loftus et al., (in press)
Habitat stability/community relationships	Kushlan, 1976b
Age and growth	Haake and Dean, 1983.
Length, mass, and calorific relationships	Kushlan et al., 1986.
Food habits	Hunt, 1953.
Sunfish spawning	Clugston, 1966.
FISHES--ESTUARINE	
Species composition and habitat relationships	Kilby and Caldwell, 1955; Tabb and Manning, 1961; Tabb et al., 1962 Odum, 1971; Tabb et al., 1974; Thayer et al., 1987; Loftus, (in review); Lindall et al., 1973.
Trophic inter-relationships	Odum, 1971; Odum and Heald, 1972.
Buttonwood Canal fishes	Roessler, 1970.
Relation of young drums to ecological factors	Jannke, 1971.
Factors affecting Whitewater Bay fishes	Clark, 1971.
Population structure, food habits, and spawning of spotted sea trout and gray snapper; early life history of spotted sea trout, red drum, gray snapper, and snook	Rutherford et al., 1982, 1983; Rutherford et al., 1986.
Age, growth, and mortality of snook	Thue et al., 1982.

Source: Compiled by CH_2MHill

Aquatic Invertebrates. Some of the aquatic invertebrate groups found in the ENP SWIM planning area have been identified and cataloged in general works, such as the mayflies (Berner and Pescador, 1988), aquatic snails (Thompson, 1984), odonates (Paulson, 1966), and water beetles (Young, 1954). Studies of specific invertebrates include work on the freshwater prawn and crayfish (Kushlan and Kushlan, 1979, 1980), and the apple snail (Kushlan, 1975). Current investigations are underway on the aquatic invertebrate community composition at short- and long-hydroperiod sites (Loftus *et al.* 1986, in press), and at nutrient-enriched locations (Urban, 1984).

Periphyton. The periphyton or microfloral components of the aquatic assemblages have been studied in terms of community composition and ecological function. Hunt (1961), Wilson (1974), Brock (1970), Wood and Maynard (1974), Van Meter (1965), and Browder (1981, 1982) studied the production of oxygen by the periphyton and other aspects of primary production. Gleason (1972) and Gleason and Spackman (1974) studied the role of periphyton, especially blue-green algae, in the processes of limestone dissolution and soil deposition. Swift (1984) and Swift and Nicholas (1987) documented relationships between periphyton community composition, water quality, and hydroperiod, primarily in marshes of the Water Conservation Areas (WCAs). Recent work includes inventories within the ENP of periphyton (Hall and Rice, 1989, unpublished data), and responses to nutrient dosing (Flora *et al.* 1987) (Table 58).

Biogeographical Relationships. Most of the freshwater invertebrate and fish species in the southern Everglades have temperate origins. Many of the algal taxa are also temperate, found in waters along the southeastern coastal plain (Swift, 1984). In general, the freshwater fish and invertebrate faunas are depauperate when compared to the remainder of the state (Gunderson and Loftus, in press). Fewer species of both groups occur in the ENP SWIM Planning Area than farther north on the Florida peninsula. For example, the northern Everglades has five species of freshwater fishes not found in the southern Everglades (Dineen, 1974; Loftus and Kushlan, 1987). The same is true for some invertebrate groups, as only a few species of mayflies (Berner and Pescador, 1988), and snails (Thompson, 1984) occur in the southern Everglades. Habitats in the Everglades may be unsuitable for many temperate fish taxa. The lentic marsh habitats provide suboptimal conditions for coastal-plain species adapted to lacustrine and riverine environments (Loftus and Kushlan, 1987). Dry-season conditions in the marshes are stressful for all aquatic species, especially those with temperate origins (Loftus and Kushlan, 1987).

The estuarine fishes and invertebrates of the ENP are derived from the Carolinean and Antillean faunas. Several are Florida endemics. Most are found both in North American and Neotropical waters, although some are mainly Neotropical and reach their northern limits in south Florida (Tabb *et al.*, 1962; Loftus, under review).

Taxonomic Diversity. Periphyton have been inventoried in the ENP but not to the degree as the WCAs (Swift, 1984; Swift and Nicholas, 1987). Van Meter (1965) found approximately 200 species of algae within the ENP, whereas Swift (1984) found more than 300 taxa in the WCAs. Hall and Rice (1989, unpublished data) and Wood and Maynard (1974) also listed algal species for the ENP. A few taxa dominate in each of the habitats, depending on factors of hydroperiod, water chemistry, etc. (Browder, 1982; Swift, 1984). Little has been written about estuarine micro-algae, except for a summary in Odum *et al.* (1982).

The larger aquatic invertebrates have received more attention than the microinvertebrates. Most macroinvertebrate groups are represented by one characteristic species. Only one species of crayfish, freshwater prawn, and amphipod occur in the Everglades (Gunderson and Loftus, in press). Cladocerans, copepods, odonates, aquatic beetles, and midges are diverse (Loftus *et al.* 1986, in press). Planorbid and physid snails are more diverse than the hydrobiid snails. In estuarine areas, decapod crustaceans are more diverse than in freshwater (Tabb and Manning, 1961), and gastropods and bivalves are very diverse.

Loftus and Kushlan (1987) list 30 species of native fishes as permanent residents of the freshwater habitats of the ENP (Table 59). They list 80 native species from freshwater in the Everglades and its mangrove habitats. The Cyprinodontidae and Poeciliidae with 11 spp. are the most speciose, along with the Centrarchidae, with 9 species. An additional seven exotic fishes occur in the Everglades and its estuaries (Loftus, in press). A total of 291 fishes has been recorded from the ENP, most from saline habitats (Loftus, under review).

Table 59. Fishes of Major Freshwater Habitats of the Southern Everglades

Common Name	Species	Eleocharis Marsh	Ponds	Sawgrass
Florida gar	*Lepisosteus platyrhincus*	UC	C	UC
Bowfin	*Amia calva*	UC	UC	UC
Golden shiner	*Notemigonus crysoleucas*	UC	C	-
Taillight shiner	*Notropis maculatus*	UC	UC	-
Coastal shiner	*Notropis petersoni*	UC	C	-
Lake chubsucker	*Erionyzon sucetta*	UC	C	-
Yellow bullhead	*Ictalurus natalis*	UC	C	UC
Brown bullhead	*Ictalurus nebulosus*	UC	UC	-
Tadpole madtom	*Noturus gyrinus*	UC	C	UC
Diamond killifish	*Adinia xenica*	UC	-	UC
Sheepshead minnow	*Cyprinodon variegatus*	C	UC	-
Golden topminnow	*Fundulus chrysotus*	C	C	C
Marsh killifish	*Fundulus confluentus*	C	UC	UC
Seminole killifish	*Fundulus seminolis*	UC	UC	-
Flagfish	*Jordanella floridae*	C	UC	C
Bluefin killifish	*Lucania goodei*	C	C	C
Rainwater killifish	*Lucania parva*	UC	-	-
Mosquitofish	*Gambusia affinis*	C	C	C
Least killifish	*Heterandria formosa*	C	C	C
Sailfin molly	*Poecilia latipinna*	C	C	UC
Brook silverside	*Labidesthes sicculus*	UC-L	UC	-
Everglades pygmy sunfish	*Elassoma evergladei*	C	UC	C
Bluespotted sunfish	*Enneacanthus gloriosus*	UC	UC	-
Warmouth	*Lepomis gulosus*	C	C	UC
Bluegill	*Lepomis macrochirus*	UC	C	-
Dollar sunfish	*Lepomis marginatus*	C	C	C
Redear sunfish	*Lepomis microlophus*	UC	C	-
Spotted sunfish	*Lepomis punctatus*	C	C	C
Largemouth bass	*Micropterus salmoides*	UC	UC	-
Swamp darter	*Etheostoma fusiforme*	UC	UC	-

Source: (Loftus and Kushlan, 1987) C=Common, UC=Uncommon, L=Localized, -=not collected

Communities of Major Aquatic Habitats. The aquatic habitats in the ENP SWIM planning area include zones that are strictly freshwater, strictly saline, and areas that are euryhaline. This discussion is restricted to freshwater and euryhaline aquatic communities. Additionally, emphasis is placed on communities of freshwater graminoid habitats, and estuarine coastal areas dominated by mangroves and salt marsh habitats. Graminoid habitats within the freshwater zones include sawgrass marshes, wet prairies and sloughs over peat (muck soils), wet prairies over marl, and alligator ponds. The estuarine habitats include mangrove forests, mangrove-lined creeks, and coastal prairies. A brief description of the aquatic flora, invertebrates, and fishes in each of these habitats is provided below.

Wet Prairies and Sloughs over Muck Soils. The spatially dominant, freshwater habitats of the southern Everglades are sawgrass marshes and wet prairies. Wet prairies provide the best habitat for periphyton, invertebrates, and freshwater fishes and are sites of major primary and secondary aquatic productivity.

The fish fauna of wet prairies (Loftus and Kushlan, 1987) are dominated numerically by small poeciliids, cyprinodontids, and juvenile centrarchids. Loftus and Kushlan (1987) found all 30 species of native freshwater fishes in this habitat (**Table 59**). Larger species, such as the Florida gar and bowfin, occur in this habitat during the wet season. Typical inhabitants are mosquitofish, sailfin molly, bluefin killifish, least killifish, sheepshead minnow, golden topminnow, and flagfish (Loftus and Kushlan, 1987). Densities range from 10-50 fish per square meter (Loftus *et al.*, in press). Biomass estimates of fishes in these habitats are low, usually ranging from less than 1 gram per square meter (g/m^2) to 5 g/m^2 wet-weight. Densities and biomass vary according to water depths, hydropattern, history, and season. Highest densities occur in long-hydroperiod marshes in spring, when water is shallow. Such marshes are prime feeding areas for wading birds and other predators.

Aquatic invertebrates typically found in the wet prairies include crayfish (*Procambarus albni*), freshwater prawn (*Palaemonetes paludosus*), and apple snail (*Pomacea paludosa*). Kushlan and Kushlan (1979) found crayfish biomass to range between 0.02 and 0.4 g/m wet-weight over an annual cycle. Prawn density ranged from 4.2 to 12.4 individuals/m over an annual cycle (Kushlan and Kushlan, 1980b). Apple snails utilize this habitat, and commonly lay their eggs on the emergent stems of spikerush (*Eleocharis* sp.) and arrowhead (*Sagittaria* sp.). Annual mean biomass of apple snails has been measured at 0.1 to 1.5 g/m (Kushlan, 1975). Loftus et al. (in press) reported densities of prawns ranging from 0 to nearly 200/m, depending on marsh hydroperiod. Crayfish densities ranged from 0 to 14/m (Loftus *et al.*, in press).

Periphyton in these habitats occur primarily as mat complexes. Mats are formed when algae grow in and around submerged aquatic plants of the genus *Utricularia*. Periphyton also grow around stems of emergent aquatic plants of the genera *Eleocharis, Panicum*, and *Sagittaria*. Algal assemblages account for dissolved oxygen fluctuations in the water column (Hunt, 1961; Wilson, 1974; Belanger and Platko, 1986). Most of the primary production in these communities is derived from algal mats (Wood and Maynard, 1974; Browder, 1981). These algae can be important food sources for crayfish (Pope *et al.* 1980) and some tadpoles (Browder, 1982).

Sawgrass Marshes. Sawgrass marshes support a poorer aquatic fauna than the wet prairies and sloughs (Craighead, 1968). The sawgrass marsh is poor habitat for most aquatic organisms, due to the high density of sawgrass culms, high summer water temperatures, and low dissolved oxygen levels. Soil surface elevations are slightly higher than in wet prairies, and therefore inundation periods are shorter during the year. The high density of sawgrass culms results in less available open water. High stem density also shades out much of the available light. The resulting habitat is much less productive of aquatic microflora and fauna.

Some algae, primarily green algae of the genus *Spirogyra*, are found growing around sawgrass culms following fires. Loftus and Kushlan (1987) only found 16 species of fish in this habitat. The fish community is mainly comprised of cyprinodontids and poeciliids, and small centrarchids (Loftus and Kushlan, 1987). Densities of fish, obtained from block-net rotenone samples have been measured at 0.8 fish/m (Loftus, unpublished data). Apple snails often utilize the sturdy sawgrass stems at the wet prairie sawgrass ecotone as egg-deposition sites.

Wet Prairies Over Marl. The marl wet prairies are found on the peripheries of the main water courses of the park, and on sites subjected to shorter hydroperiods during the year due to slightly higher topography or better drainage.

Periphyton compositions on these sites vary according to hydroperiod (Van Meter, 1965; Browder, 1981) and surface water ionic content (Swift, 1981; Swift and Nicholas, 1987). Browder (1981) found blue-green algae to comprise 90% of the algal volume, with the predominant genus being *Scytonema*. The blue-green algae reestablish much more quickly following rehydration, and therefore are better adapted to shorter periods of inundation. Waters higher in dissolved calcium carbonate, chloride, and sodium support a less diverse flora (Swift and Nicholas, 1987). Periphyton biomass has been reported to range from 45 to 447 g/m (Gleason and Spackman, 1974); and from 7 to 1,700 g/m (Browder, 1981). Total biomass has been reported as high as 2,000 g/m (Wood and Maynard, 1974). Biomass totals have been correlated with soil organic matter (Browder, 1981).

Primary productivity of the periphyton has been linked to secondary trophic production and soil deposition. Van Meter-Kasanof (1973) measured an average net production of 2.68 g/m/day (978 g/m/year). Browder (1981) measured net production from 0 to 366 g/m. Gleason (1972) and Gleason and Spackman (1974) determined the role of the blue-green algae in these prairies in precipitation of the calcitic mud or marl.

These prairies appear flat on first glance, but actually provide much relative variation in micro-topography (White, 1970). The numerous solution holes, which are 50 to 75 centimeters below the surrounding soil surface elevations, provide important refugia for aquatic organisms. Wood and Maynard (1974) discussed the algal components of the solution holes and their importance as recolonization reservoirs for marsh algae. The solution holes are the primary crayfish and fish habitats, but due to frequent drying and water level fluctuation support low numbers of organisms and lower diversity than the longer hydroperiod peat marshes (Loftus and Kushlan, 1987). The fishes and invertebrates found in the marl prairies support early dry-season feeding aggregations of wading birds.

Alligator Ponds. The alligator ponds are the deepest natural habitats in the freshwater complex and the smallest in areal extent. Generally, macrophytic vegetation is limited within the pond to small stands of bladderwort (*Utricularia*), or waterlily (*Nymphaea odorata*) and spatterdock (*Nuphar luteum*). The ponds are often surrounded by willow and other marsh vegetation species. Algal blooms occur in the ponds as water levels decline and nutrients become concentrated. The bottom of many ponds is covered by a layer of globular blue-green algae (Wood and Maynard, 1974).

Alligator ponds support the largest fish species found in the Everglades, and the densities and composition of species change depending upon water depths in the adjacent marshes. Loftus and Kushlan (1987) found small numbers of yellow bullheads, Florida gar, and large centrarchids in the open water areas during wet seasons, with mosquitofish, sailfin mollies, and golden topminnows around the margins. They found that large fish species dominate pond biomass as water levels fall during the dry season. These ponds serve as refugia during the dry season, when fish and many invertebrates from the surrounding marshes migrate into the ponds which often contain the only remaining surface water in the area. Due to the seasonal concentration of food resources, the ponds are the focus of feeding and nesting activities for birds and alligators throughout the year.

Mangrove Creeks/Swamps/Coastal Prairies. These habitats form the vast estuarine complex downstream of the Everglades freshwater marsh system; and are dependent upon freshwater input from upstream marshes for their existence. The physical aspect of this region is extremely diverse and has been described by Odum (1971), Odum *et al.* (1982), and Schomer and Drew (1982). The mangroves, especially red mangrove (*Rhizophora mangle*), border stream channels that cut deeply into the freshwater marsh system. Between the stream channels are extensive areas of wet prairie and sawgrass marshes. Closer to the coast, the red and black mangroves (*Avicennia germinans*) form huge swamps dissected by stream channels and interrupted by stretches of coastal prairies of *Spartina* spp., *Juncus roemarianus*, and other species. These habitats experience wide variations in environmental conditions over daily, seasonal, and annual periods.

Freshwater and estuarine animals move in response to changing conditions and to their life-cycle requirements (Tabb *et al.*, 1962; Roessler, 1968; Odum *et al.*, 1982; Schomer and Drew, 1982), resulting in this region having very high annual species diversity and productivity. The faunas are typically mixtures of freshwater and euryhaline species, dominated by truly freshwater taxa at the upstream sections of creeks and marshes and becoming more marine-influenced nearer the coast. Loftus and Kushlan (1987) found 69 fish species in freshwater in this region; many of those species were euryhaline taxa which had used the stream channels to enter freshwater reaches. Penetration of this habitat by euryhaline species was aided by high ionic (calcium) concentrations in Everglades waters (Hulet *et al.*, 1967). A similar situation was reported by Odum (1971) and Odum *et al.* (1984). Loftus and Kushlan (1987) found small fish species using mangrove prop roots for shelter and grazing; larger species inhabited the main channels. Odum (1971) established the importance of this region as a nursery for many important game and forage species.

Water levels, salinity, tides, sea-level, rainfall, and freshwater flows are major factors controlling the aquatic environment of the region. The stream channels vary slightly in water level during the year but fluctuate greatly in salinity and water chemistry. Stream channels may be connected to pools, swamps, and prairies during high-water periods, then isolated in the spring (dry season). Water-level changes are especially pronounced in the swamps and coastal prairies, large areas of which often dry in the spring.

Odum (1971), Heald (1971), Odum and Heald (1972), and Heald *et al.* (1974) described the importance of mangrove leaves and detritus to estuarine food webs and export of carbon to marine areas. Related concepts are discussed by Odum *et al.* (1982), especially nutrient cycling, hypotheses on energy flow, importance to wading birds as feeding/nesting sites, and management options.

Ecological Relationships. The distribution, composition, and abundance of aquatic communities are affected by both abiotic and biotic factors. These factors vary both spatially and temporally, resulting in a complex, ever-changing mosaic to which the flora and fauna must adapt. The dominant abiotic factors which shape the aquatic communities include hydrological patterns, water quality, fire, and climatic events. Biotic interactions, such as competition and predation, shape the communities as well, but less study has been devoted to the biotic factors compared to the information gathered on abiotic factors.

Hydrologic Influences. The wet summers and dry winters of the region result in an annual hydrologic pattern in which water levels reach annual maxima in late summer and early fall, then dry to annual minima in the spring. Aquatic organisms exhibit a variety of adaptations to the changing conditions associated with this alternating cycle of flood and drought. For example, during the dry season, algal assemblages become desiccated and remain dormant until rehydration the following summer. Invertebrates, such as the crayfish, burrow into the ground during drought, maintaining contact with the water table (Kolipinski and Higer, 1969). Cladocerans produce resting eggs, resistant to desiccation (Loftus *et al.* 1986, in press), as do some fishes (Harrington, 1959). Some small fishes and invertebrates survive low dissolved oxygen levels by utilizing the oxygen rich water surface where diffusion occurs (Lewis, 1970) or using atmospheric oxygen (McCormack, 1967; Loftus and Kushlan, 1987).

Mobile organisms, such as fishes and prawns, follow the declining water levels and become concentrated into the remaining marsh puddles and alligator ponds. Densities as high as 500 fish/m are not unusual (Loftus, unpublished data). Dry season crowding may lead to mortality from parasites (Kolipinski, 1969). In prolonged droughts, intolerant species, such as sunfish, die (Loftus and Kushlan, 1987). The onset of the wet season results in short-term decreases in density, species diversity, and biomass (Loftus et al. in press) as marshes reflood and remaining organisms disperse into the surrounding wetlands.

In regions having shorter hydroperiods, whether natural due to topography or anthropogenic because of drainage, reduced diversity, density, and biomass of fishes and invertebrates has been observed. (Loftus et al. in press). Evidence points to the lack of adequate food base (detritus and usable algae) for those organisms. (Loftus *et al.* in press). Periphyton communities may shift species composition under different hydropattern regimes as drought-tolerant forms are selected (Van Meter-Kasanov, 1973; Browder, 1981).

Water flow from the freshwater Everglades is important in maintaining estuarine salinities suitable for meeting life-history requirements of associated organisms. Although not well demonstrated, it has been postulated that the freshwater input carries nutrients and carbon into the estuary (Odum *et al.*, 1982; Wood and Maynard, 1974). Wading bird predation and movement of fishes out of freshwater and estuarine habitats are significant sources of carbon loss from those systems.

Water Quality. Water quality is a major factor in the configuration of current aquatic communities. Direct rainfall is thought to have historically provided most of the water and nutrients to the Everglades (Davis, 1943a; Parker *et al.* 1955; Waller and Earle, 1975). Nitrogen and phosphorus concentrations are naturally low in the marsh waters, and phosphorus especially is thought to be limiting to periphyton (Swift, 1984; Swift and Nicholas, 1987).

Water quality has been correlated with periphyton community composition (Swift, 1984; Swift and Nicholas, 1987). Changes in water quality due to drainage or nutrient addition can favor species of pollution-tolerant algae, and potentially could lead to food web alterations (Swift and Nicholas, 1987; Wood and Maynard, 1974).

Climatic Events and Fire. Other ecological factors that affect aquatic organisms in the Everglades include weather conditions such as hurricanes and cold fronts. Hurricanes periodically strike the Everglades with force sufficient to destroy mangrove forests, open areas to strong sunlight, and cause oxygen depletion of waters because of decomposition of organic matter following storm passage. (summarized by Odum *et al.*, 1982). Reark (1961) described how Hurricane Donna piled up windrows of a periphyton-*Utricularia* mat in Shark Slough. Such large scale disruption of aquatic habitats has immediate and long-term effects on organisms.

Cold temperatures associated with severe cold fronts rarely affect aquatic animals in the Everglades marshes but have killed estuarine species, such as tarpon and snook, with tropical affinities.

Fires, especially those that occur in marshes during severe drought years, may consume organic soils, cause direct mortality of organisms, and change successional patterns of vegetation (Wade *et al.*, 1980; Gunderson and Loftus, in press). In estuarine areas, fire is important to maintaining the presence of coastal prairies against incursion by fire-intolerant mangroves (Wade et al., 1980). Because coastal prairie pools are important wading bird feeding sites, a reduction of that habitat in favor of mangroves would likely result in declines in wading birds and forage fishes.

Trophic Interactions. The primary biotic factors that affect both flora and fauna of ENP are predation and competition. While both competition and predation affect the composition, abundance, and distribution of the biota, predation is a major factor in the flow of energy throughout the food web.

In the WCAs and ENP the food web is a detrital based system composed of material contributed by the decomposition of herbaceous aquatic macrophytes and algal material derived from the periphyton community with relatively little contribution from phytoplankton (Odum, 1971; Gunderson and Loftus, in press; Loftus *et al.*, in press). Due to its sparse concentration, phytoplankton does not contribute appreciable fixed carbon to this system rather the majority of primary production in this system occurs in herbaceous aquatic macrophytes and the periphyton community (Hunt, 1961; Van Meter, 1965; Wood and Maynard, 1974; Wilson, 1974; Browder *et al.*, 1981, 1982;). Mangrove productivity is additionally important to the estuarine systems of ENP as a source of secondary production of detritus (Odum, 1971; Heald, 1971). Generalized food webs supported by grazing and detrital pathways for the freshwater systems of ENP are presented by Gunderson and Loftus (in press).

Macrophytes and periphyton (submerged or floating associations of dominant blue-green algae with filamentous green algae, desmids, and diatoms) are the major primary producers of the autotrophic food web. They are consumed by micro-invertebrates, as well as small fish, such as sailfin molly, flagfish, and sheepshead minnow (Kolipinski and Higer, 1969). Dead organic matter, and its associated microbes, form the base of the detrital food web. Detritus is consumed by cyprinid fish and small invertebrates such as microcrustaceans, midges, and oligochaetes (Gunderson and Loftus, in press).

Life histories of certain animals can determine trophic level. For example, many insects spend part of their life as aquatic larvae and their adult stage as terrestrial. Each stage is important, for the aquatic larvae provide energy to aquatic predators, while adults are an integral part of the terrestrial energy flow. Examples of insects with aquatic and terrestrial life stages are caddisflies, mayflies, dragonflies, damselflies, and mosquitoes. Because of the sheer numbers of insects in the planning area, their contribution to the food web is important. But the ecology and trophic interactions of this group have not been studied intensively, just as many of the biotic interactions in the Everglades are poorly understood.

Fish are the top aquatic consumers within the aquatic food chain, and feed on various trophic levels below them. Fish, as well as other aquatic animals such as crustaceans, snails, and tadpoles provide a vital link to terrestrial food webs. Heterotrophs such as wading birds, snail kites, mink, otter, and the alligator depend on the health and vitality of aquatic communities in the Everglades.

Exotic Species. Exotic aquatic taxa are abundant in southern Florida (Courtenay and Hensley, 1979), and common within the ENP SWIM Planning Area (Loftus, in press). The major habitats for exotic species are canals constructed for water management purposes, and borrow pits used as sources of limerock (fill material). The canals also provide means of conveyance for these organisms to move rapidly into undisturbed, natural habitats.

Aquatic weeds that occur in the canal system include the floating aquatic weed, water hyacinth (*Eichhornia crassipes*), and the submerged aquatic weed, hydrilla (*Hydrilla verticillata*). Both species are found in Canal L-67 Extended. Generally Canals L-29, L-31W and C-111 are kept free of aquatic plants by chemical and physical means to maintain optimum flow capacity. Proliferation of these aquatic weeds is generally restricted to man-made, physically-disturbed areas. Even when the exotic weeds occur in areas adjacent to the natural marshes, these plants show little sign of colonizing the native system.

Exotic aquatic invertebrates which occur in canals and marshes include species of Neotropical dragonflies and several snails (*Marissa* and *Melansides*). Otherwise, few exotic invertebrate species are considered problematic. Although the exotic fishes of southern Florida reach their greatest abundance in the canals of the southeast coast, the natural marshes have been invaded to a relatively limited extent. Loftus and Kushlan (1987) found 12 established exotic species, most belonging to the Cichlidae. Loftus (in press) reported seven established species in Everglades National Park (**Table 60**). The walking catfish and black acara have invaded natural areas, being most successful in those habitats where few native species can survive. The blue tilapia, mayan cichlid, oscar, and pike killifish inhabit the borrow pits along Anhinga Trail in Taylor Slough. Several exotic fishes have colonized estuarine habitats (Loftus, in press).

A great deal has been written about the potential impacts of exotic fishes on native aquatic communities (Courtenay and Hensley, 1979; Loftus in press). Known impacts in Everglades waters include nest-site displacement of native sunfishes and largemouth bass by blue tilapia; predation by walking catfish, oscars, and pike killifish; and food web alterations by blue tilapia, spotted tilapia, and others. Several species are now be utilized as prey items by wading birds and alligators. Factors limiting colonization of natural habitats by neotropical exotic fishes include periodic cold spells which drop temperatures below lower lethal limits (Shafland and Pestrok, 1982; Loftus, in press), and ecological interactions with native species.

Table 60. Exotic Fishes Established in Everglades National Park

	Taylor Slough	Shark Slough	Estuarine Zone
Family Clariidae			
Walking catfish (Clarias batrachus)	X	X	X
Family Poeciliidae			
Pike killifish (Belonesox belizanus)	X	X	X
Family Cichlidae			
Oscar (Astronotus ocellatus)	X	X	
Black acara (Cichlasoma bimaculatum)	X	X	
Mayor cichlid (Cichlasoma urophthalmus)	X		X
Blue tilapia (Oreochromis aureus)	X		X
Spotted tilapia (Tilapia mariae)	X	X	X

Source: (Loftus, in press; Loftus and Kushlan, 1987)

Threatened and Endangered Species and Species of Special Concern. No freshwater aquatic species in the ENP SWIM planning area are listed as threatened or endangered by the Federal government or the State of Florida. The Florida Committee on Rare and Endangered Plants and Animals (FCREPA) lists a killifish, the rivulus (*Rivulus marmoratus*) as threatened. The rivulus occurs in estuarine habitats in Everglades National Park (Tabb and Manning, 1961; Loftus and Kushlan, 1987), but it has rarely been collected. It's rarity may be an artifact of inappropriate collection techniques; it is possible that the rivulus is actually more abundant than is currently documented. Too little is known about the population sizes of most aquatic invertebrates to ascertain whether any deserve to be listed.

The Florida tree snail, *Liguus fasciatus*, is not considered an aquatic organism but warrants special mention. *Liguus* was avidly hunted by collectors and amateur scientists in the hammocks of ENP. Beard (1938) reported over collection and the destructive practice of setting fires to reach collection sites. The Florida Game and Freshwater Fish Commission lists the Florida tree snail as a species of special concern.

Threats to Aquatic Resources. Urban and agricultural developments in southern Florida, which are inexorably tied to water management practices in the Everglades, are the major agents threatening aquatic resources in the planning area. Direct loss of Everglades wetlands began with the first urban developments at the turn of the century and continue to the present day. Agricultural development, first by farming finger glades followed by rock-plowing of short hydroperiod peripheral marshes irrevocably converted wetlands to other purposes.

Most development of Everglades wetlands would have been impossible without concurrent drainage via the regional canal system. Urban and agricultural development in, and neighboring, the Everglades basin represent threats to aquatic resources because they potentially can result in degraded quality of waters delivered to the oligotrophic ENP wetlands.

Water-quality degradation has been implicated as a cause of shifts in periphyton communities in Everglades marshes (Swift and Nicholas, 1987). Diverse periphyton communities change to less diverse assemblages dominated by pollution-tolerant genera. Such changes may produce measurable changes in marsh food webs. Additionally, contaminants like pesticides and heavy metals may be concentrated by aquatic organisms through the process of biomagnification. Even the human population may be affected if significant amounts of fishes with high contaminant loads are consumed. Recent detection of mercury in bass collected from the WCAs and other Southern Florida areas has heightened regional awareness of this ever-present threat to aquatic systems.

The loss of peripheral wetlands is thought to be a major factor in changes of nesting wading bird numbers and the timing of their nest initiation in the southern Everglades (G. C. Ogden and W. B. Robertson, Jr., personal communication). Many of those short-hydroperiod wetlands, which served as early dry-season feeding habitats for wading birds, are now lost because of wetland conversion for human land uses. Loss of wetlands and associated aquatic habitats is a continuing threat to these natural systems.

The water management practices associated with urban and agricultural development have had serious impacts on aquatic resources in this planning area. The case-history of Northeast Shark River Slough offers many lessons on the effects of water-flow reductions on aquatic communities (Loftus *et al.* in press). Reduction of marsh hydroperiod in this formerly long-hydroperiod wetland has resulted in a periphyton community similar to that of naturally short-hydroperiod marshes, low levels of soil organic matter, low fish and invertebrate population levels, and low use by wading birds (Fleming, in press). The entire food web appears to have been altered by the reduction of hydroperiod, resulting in a hydrologically altered marsh system.

Loftus and Kushlan (1987) suggested that marshes subjected to drainage are more susceptible to invasion by exotic fishes. Conversely, disruption of natural water-level fluctuations by artificial maintenance of deep water allows build-up of an unconsolidated organic floc (Crowder, 1974), may change community structure (Kushlan, 1976b), and alter energy flow in the marsh. Prolonged high-water levels may interfere with alligator nesting and may prevent wading birds from using marshes for feeding.

The infrastructure of the regional water management system can potentially affect aquatic communities in several ways. Rapid shunting of poor quality waters to sites remote from the sources may occur. Canals also route large quantities of water to areas where ecological damage can result from unnaturally- rapid water level increases. Levees prevent aquatic animals from freely moving across the Everglades system, and associated canals may direct animals from marshes so they are unavailable to predators. The canal system also may act as a pathway for movement and invasion by exotic fishes and invertebrates into natural habitats.

Many of the problems and threats facing aquatic resources in the Everglades are directly related to inadequate understanding of natural processes and ecological relationships. Although understanding of the system has improved over time, some basic questions remain that require intensive research effort. A major unanswered question deals with the relation of upstream water management on estuarine processes and estuarine animal life histories. Attention and funding should be directed at basic system processes and the consequences of altering those processes.

10. Land Uses

Historical Land Use. The Water Resources Atlas of Florida (Fernald and Patton, 1984) presents a comprehensive overview of historical land use activities in south Florida which have affected water flowing to the ENP SWIM Planning Area. Much of the material presented in this section is taken from this source; other sources are noted where appropriate.

In a reconnaissance study prior to the establishment of ENP, Beard (1938) summarized the human activities in the proposed park area. He reported some commercial and sport fishing, extensive hunting of plume birds, especially American and Snowy Egrets, and hunting or trapping of animals such as raccoon, bobcat, otter, and alligator. Lumbering occurred on a small scale within the planning area; logging was primarily on Caribbean Pine. A sawmill was located in Long Island Key, where most of the timbering operations occurred (Beard, 1938).

Agricultural activities were generally small in scale and seasonal (farming from November to February through April). Beard (1938) reported farming near Royal Palm State Park, along the Ingraham Highway. Farms were usually ditched and diked. Unfavorable conditions, such as high water and mosquitoes, precluded significant farming in the area. The "Hole-in-the-Donut", located in the south ridge of Long Pine Key, was considered highly productive farm land. At maximum cultivation, this area was as large as 4,000 hectares (10,000 acres). Much of the marginal land was abandoned from the 1940s to the 1960s. By 1975 all agriculture had ceased.

In an attempt to prevent the spread of a cotton borer to northern cotton-producing states, the U.S. Department of Agriculture undertook a campaign to eradicate wild cotton in the southern Florida mainland. The wild cotton was pulled out and burned. These activities caused some hammock destruction (Beard, 1938). Other human activities which have affected the ENP included; West Indian snail, "Lig", hunting, which caused some destruction to hammocks; plant collecting, primarily orchids, palms, and ferns; and frog-hunting.

The Everglades National Park was created in 1947. Its size at that time was 460,000 acres (190,000 hectares) (National Park Service [NPS], 1979). As a result of several land acquisitions during the 1950s, the ENP expanded to its current size of 1,400,533 acres (566,796 hectares) (NPS, 1979). Land use activities within the ENP have been directed at preserving the natural environmental setting while allowing low-impact human activities associated with education, research, and recreation. Such activities within the park are primarily located along State Road 27, which runs from the park entrance at Royal Palm southwest to Flamingo.

Present Land Use. The Draft Master Plan of the Everglades National Park (NPS, 1979) presents five classifications for land within the ENP. These include:

- o Class II--Outdoor Recreation Areas: major access roads and major developments to which they lead
- o Class -Natural Environmental Areas: buffer lands around Class II lands, waters of the Gulf Coast and Florida Bay, and major inland waterways
- o Class IV--Outstanding Natural Areas: habitats and rookeries of endangered species, mud- and grass banks of Florida Bay, parts of the Ten Thousand Islands and the Shark River Slough
- o Class V--Primitive Areas: the remaining undeveloped and roadless lands and most submerged lands that are not otherwise classified

- o Class VI--Historical and Cultural Areas: indian mounds and cemeteries, land reserved for Miccosukee Indians, and other historic areas

There are no Class I--High Density Recreation Areas in the park.

Land use Effects on Water Quality and Hydrology. Alteration of regional hydrology, combined with agricultural and residential development land uses, in the East Everglades have adversely affected the study area through

* overdrainage, resulting in loss of habitats
* stabilization of water levels, interrupting the periodic wet/dry cycle which many of the native species need
* interruption of the sheet flow of water across the park, resulting in disruption of the normal water delivery patterns.

In addition to these hydrologic effects, degradation in the quality of waters delivered to the ENP could result in further changes in the natural systems within the planning area. These problems are aggravated by continued growth in demands for water supplies in southeast Florida; supplies which are primarily provided by the Lake Okeechobee water system. Growth in these water demands increasingly depletes waters from the Conservation Areas which might otherwise be available for the Park. Water delivery problems are the result of identifiable and specific human activities on land adjacent to the ENP. In a broader, regional perspective, these problems are integrally linked to economic development in southeastern Florida.

11. Recreation Resources.

The largest remaining subtropical wilderness in the coterminous United States, Everglades National Park (ENP) is a unique and highly diverse wetland system which attracts visitors from around the globe. Administered by the National Park Service, the ENP has been designated a World Heritage Site and an International Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO) for its outstanding universal and ecological values. Most remarkable among these is the freshwater river about 6 inches deep and 50 miles wide which moves slowly and imperceptibly through sawgrass prairies to cultivate a vast diversified marshland. The park also contains cypress forests, pine uplands, subtropical hardwood hammocks, marl and limestone flatlands, freshwater streams and sloughs, spring-fed lakes, mangrove estuaries, and marine bays. These ecosystems support 14 federally listed endangered and threatened species and hundreds of other flora and fauna.

ENP is located on the southwest tip of Florida and comprises 1.4 million acres of wetland, upland, and water, including most of Florida Bay. Almost 1.3 million acres are designated as part of the National Wilderness Preservation System. Another 107,600 acres is proposed for park expansion in the East Everglades Area directly east northeast of the present park boundary.

In 1988 the park attracted 1,071,373 visitors from all over the nation and the world. ENP was the 8th and 10th ranked primary destination of all surveyed tourists entering the state by air and car, respectively, in 1988. Visitors came to participate in such recreational opportunities as nature study, sightseeing, saltwater fishing (snapper, redfish, trout), freshwater fishing (largemouth bass), boating, canoeing, bird watching, hiking, and camping (primitive and improved). Although charter fishing, group tours, and similar guided excursions are offered, park management is mainly oriented toward providing primitive recreation experiences consistent with ENP's designation as a national wilderness area. In 1988, approximately 64 % of all recreation use occurred in the five months from December through April. Many visitors avoid the rainy summer season with its large numbers of mosquitoes. However, summer use is on the rise, primarily from European visitors. The park's main entrance is through the Main Visitor Center on the eastern boundary, south of Miami. Internal access is highly limited and reflects ENP management objectives for ecological preservation and compatible, limited use, consistent with a wilderness recreation experience. Beginning at the Main Visitors Center, one 38 mile road traverses the park. Most of the park is reached only through backpacking or boating.

In keeping with its primitive nature, outdoor recreational facility development is minimal. It includes: four visitor information centers/nature observation sites, 43 developed campsites, primitive camp sites walking trails, a 99 mile Wilderness Waterway and 32 additional canoe trail miles, boat ramps, and other day use recreation facilities. In addition, NPS licenses the following commercial concessions: 3 air taxis to Ft. Jefferson National Monument, 24 charter boats, 6 canoe outfitters, 3 nature photographers, and 1 bus company.

12. Economic Significance.

ENP's economic significance encompasses at least two primary perspectives. One is the value of the public recreation offered by the park itself. Another is ENP's direct and indirect contribution to the private U.S. economy, which might be further narrowed to identify the specific contributions to the local, South Florida regional, and State economies.

ENP's contribution to Florida's $24.3 billion tourist economy (1988, U.S. Travel Data Center) can not be meaningfully summarized on the basis of existing data. An estimate of the number of out-of-state visitors is hazarded at roughly 500,000, or almost half of all ENP visitation; however, this estimate is based on 1988 state tourism data which lacks a statistically significant sample size. Nevertheless, extrapolation from this sample would show that about 60% of these out-of-state visitors arrived via air transportation, while roughly 40% arrived by car, on extended journey over the length of Florida.

Direct contributions to the Florida economy would include variable trip expenditures by out-of-state tourists for gas, lodging, food, site fees, and similar items. Out of state residents and instate residents of northern Florida would contribute to the regional south Florida economy and the local economies of Monroe, Collier, and Dade Counties. However, most Florida tourists attend more than one destination attraction so that the sole contribution of ENP to the regional and State tourist industry can not be isolated without special survey. Several canoe and camp outfitters, food establishments, and other tourist-oriented private businesses on the outskirts of ENP in Monroe, Collier, and Dade Counties are based in the recreational use of ENP.

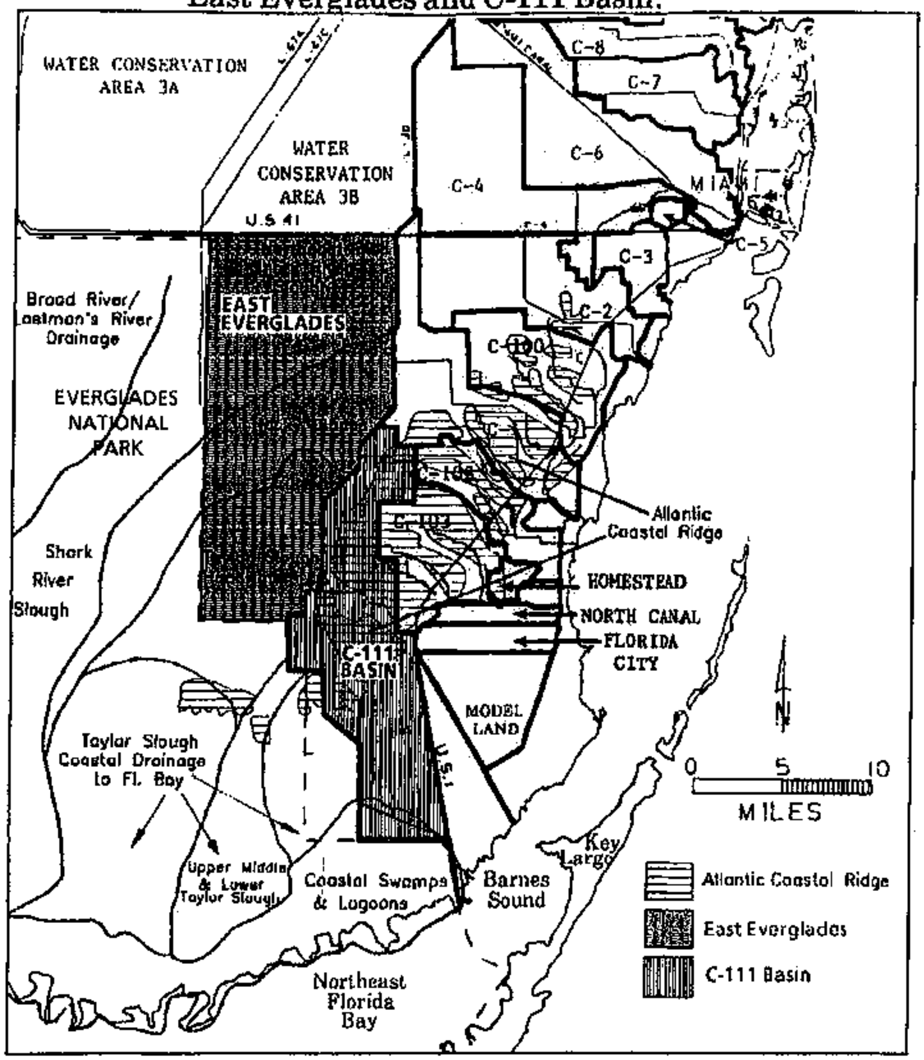
This Page Intentionally Left Blank

F. C-111 BASIN AND EAST EVERGLADES.

1. Physical Features of the C-111 Basin and East Everglades

Introduction. Two surface water drainage basins are located east of ENP and west of the coastal basins, the East Everglades and the C-111 Canal basin (**Figure 50**). The East Everglades lies generally west of L-31N, east of ENP, south of WCA-3,

Figure 50. Location and Major Physiographic Features of the East Everglades and C-111 Basin.



Source: Adapted from Cooper and Lane, 1987a and Schomer and Drew, 1982

and north of the eastward extension of the park boundary where it intersects L-31W . The C-111 Canal basin includes lands that lie generally southeast of the East Everglades and west of the coastal basins. Present land use/land cover characteristics of these two basins indicate that 85% of the area contains native vegetation or open land. Approximately 5% of the combined area of these two basins is developed for urban uses and 10% is used for for agriculture.

This region includes portions of Shark River Slough and the headwaters of Taylor Slough which historically provided significant surface water inflows to Everglades National Park (**Figure 50**). Drainage from the East Everglades and C-

111 is ultimately discharged into Northeast Florida Bay and Barnes Sound. Surface water runoff from the C-111 basin represents an important source of freshwater flow into the sensitive estuarine ecosystems of Northeast Florida Bay and Barnes Sound.

Much of the land in these basins is occupied by extensive native Everglades plant communities consisting of freshwater wet prairies, sawgrass stands, aquatic sloughs and tree islands, which eventually intergrade into dwarf mangrove communities which fringe the shoreline of Northeast Florida Bay and Barnes Sound. The East Everglades and the C-111 basin represent critical buffer zones between the pristine wetlands of ENP and the rapidly expanding urban and agricultural development in the eastern coastal basins. Most of this region has been recently identified for acquisition to protect sensitive ecosystems by expansion of ENP. Approximately 50,000 of this 107,000 acre addition to ENP became part of ENP on October 1, 1991.

The available surface water quality data for these basins, in general, indicate that water quality is very good with low levels of dissolved nutrients. Occasionally, samples indicate elevated levels of nutrients and dissolved solids, as well as the presence of detectable concentrations of pesticides. There is increasing concern about the quality of water discharged from these basins to ENP.

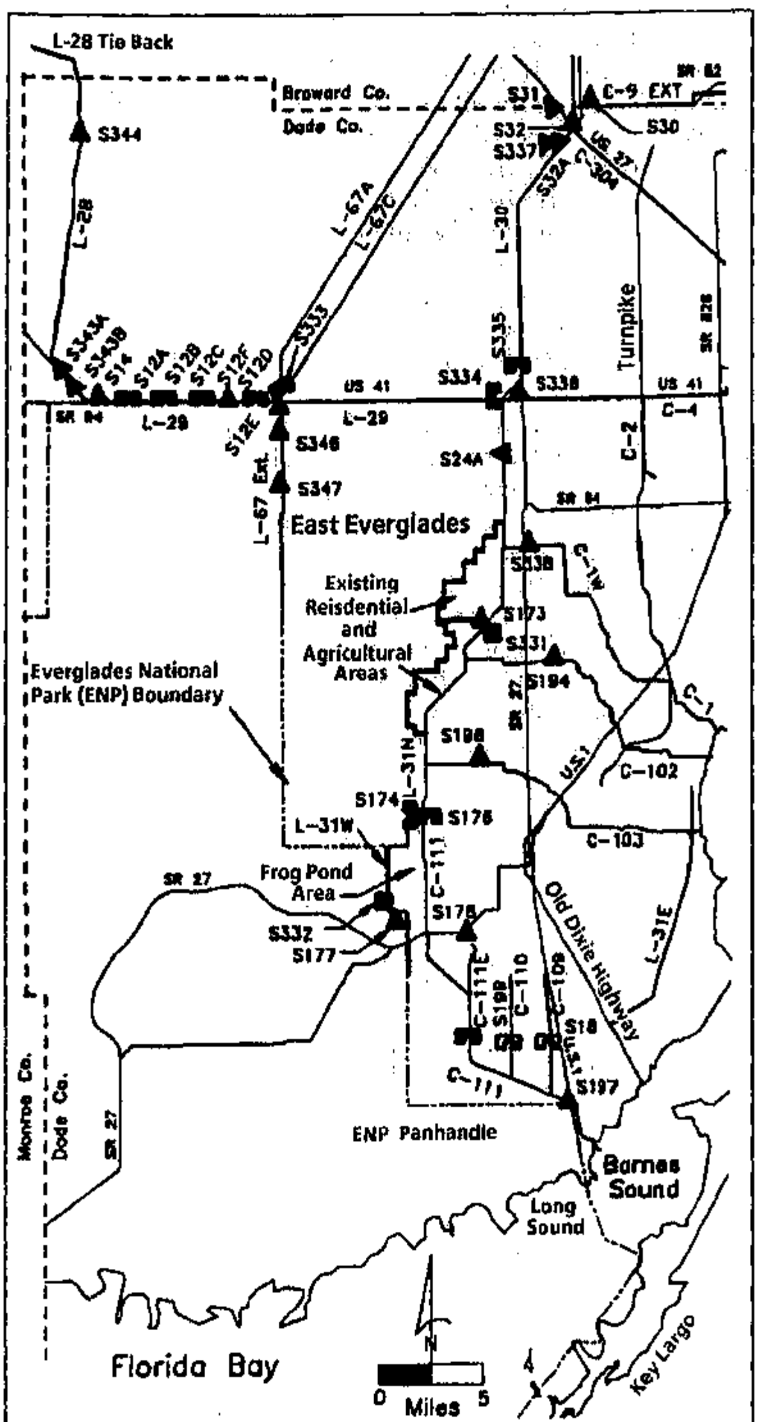
Groundwater quality is also generally very good. Potential problems have been identified for contamination of groundwater with agricultural chemicals, stormwater runoff and saltwater intrusion. These problems are especially significant due to the location of a number of existing and proposed public water supply wellfields in the C-111 Canal Basin and adjacent areas

Continued population growth and development in recent years have created a number of water management problems in this area. Construction of the L-29 levee in WCA-3B coupled with completion of the L-67 extension canal and levee in ENP, cut off sheet flow to the central portion of Shark River Slough (**Figure 51**). These alterations isolated the interior of ENP from a primary source of natural sheet flow of surface water and altered vegetation characteristics within the eastern portion of ENP that had developed in response to that flow. Construction of the C-111 Canal system was never fully completed. Operation of the existing components of this system results in occasional large discharges of fresh water into Barnes Sound and Manatee Bay. The South Dade Conveyance System (SCDS) was designed and built to provide additional water to ENP and to support agricultural production in South Dade County. This system has resulted in increase in the amount of water discharged to the southern end of the C-111 Canal system.

In response to these problems, the District and the Corps are developing a series of management plans to improve water deliveries to these basins. These plans include a "Rainfall Plan" to improve water deliveries to Taylor Slough; the C-111 Basin Interim Plan to address short-range water management problems in the C-111 Basin; and the C-111 Canal and ENP Water Delivery General Design Memorandums to develop long-range water management solutions.

Major Hydrographic Units. The EEA and C-111 Canal basin contain a number of adjacent land areas that are both hydrologically and ecologically interconnected (**Figure 51**). These areas are divided into a number of units, based on physiography, canals, drainage patterns and land uses. The boundaries of these areas may overlap so that a given point can lie within one or more units:

Figure 51. Major Physical and Water Conveyance Features of the East Everglades and the C-111 Canal Basin



Source: SFWMD

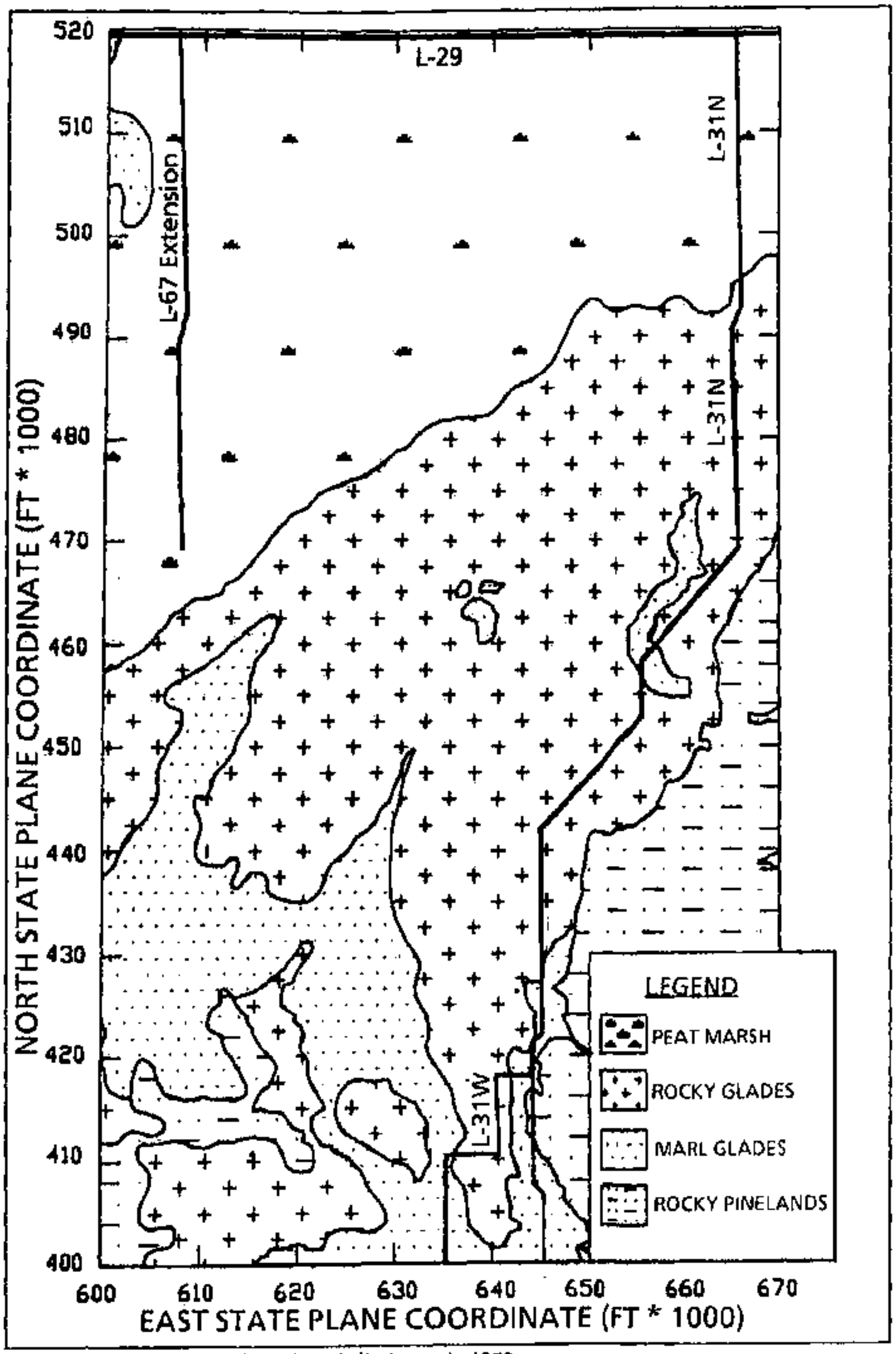
East Everglades Area (EEA). The EEA is bounded in the north by the L-29 levee along WCA-3, on the east by the L-31N levee, on the west by ENP and in the south by the eastern extension of Everglades National Park border where it intersects with L-31W. The "8 1/2 Square Mile Area" is a developed area of rural land use within the EEA, adjacent to L-31N. The East Everglades also includes the historic main portion of Shark River Slough, generally called the Northeast Shark River Slough (NESRS). This area was physically and hydrologically separated from the rest of Shark River Slough after the addition of the L-67 Extension Levee (Neidrauer and Cooper, 1989). The EEA also includes the Rocky Glades, which form a transition area between Shark River Slough to the west and the headwaters of Taylor Slough to the south (**Figure 50**). Water deliveries through the EEA are critical for restoration of the historic distribution, hydroperiod and flow to Shark River Slough and the subsequent receiving ecosystems of ENP. The East Everglades include portions of three physiographic areas--Shark River Slough, Rocky Glades and Taylor Slough. The East Everglades area is composed of peat, marl soils, or rockland/rockdale soils on lime rock and the entire region is underlain by by Miami oolite (Hoffmeister *et al.*, 1964; Hofstetter and Hilsbeck, 1980).

Shark River Slough. Shark River Slough provides the primary inflow of water to the ENP, and whose main portions lie within ENP boundaries. Shark River Slough is a natural wetland depression that contains organic sediments made up of both shallow and deep peats (Davis, 1943a; Stephens, 1943). Historically, the Shark River Slough drainage originated in Water Conservation Area 3. Water flowed southeastward in an arc that swept through the area that is now called the East Everglades and curved back to the west to flow down the main channel of the slough through the heart of ENP at Shark River Valley (Beard, 1938; Davis, 1943a). The main portions of the northern slough are contained in both ENP and the East Everglades. The slough is presently divided in the northern portion by the levee, L-67E. The restoration of the historic structure and function of Shark River Slough is critical for the restoration of ENP

Rocky Glades. Shark River Slough is bounded on the east by a slight topographic rise that partially comprises of the western edge of the Miami Rock Ridge (Davis, 1943a; Parker *et al.*, 1955). The area that lies north of Taylor Slough and south and east of Shark River Slough is known as the Rocky Glades. The Rocky Glades act as a hydrologic barrier to separate surface waters of Shark River Slough on the north from the headwaters of Taylor Slough to the south (Parker *et al.*, 1955; McPherson *et al.*, 1976; DERM, 1980). The Rocky Glades contain sparse, short-hydroperiod wetland vegetation. The portion of Rocky Glades that lies within the East Everglades is generally characterized by thin Rockdale or Redlands soils that were described by Davis (1943a) as essentially rocklands not covered by soil (**Figure 52**). This area, in the northeast central portion of the East Everglades, is under pressure for urban development. Portions of the Rocky Glades, located along the levee, are currently under cultivation in many places. Cultivated lands extend south from this area, along the levee, through the Taylor Slough headwaters to the area called the Frog Pond, west of Florida City.

Taylor Slough. Taylor Slough is a 158 square-mile (247 square kilometer) wetland system that extends more than 20 miles (32 km) from headwaters that begin in the central portion of the East Everglades to the coastal mangrove fringe along Florida Bay (Johnson *et al.*, 1988) (**Figure 50**). The slough crosses parts of the C-111 basin, but the major portion of this system lies within ENP. Headwaters of Taylor Slough provide the main inflow to eastern ENP. Taylor Slough headwaters include the extreme southern portion of the East Everglades, the area known as the Frog

Figure 52. Soil Associations of the Northeast Shark River Slough Area.



Source: Soil Associations based on Gallatin et al., 1958

Pond (DERM, 1980). Taylor Slough is the central component of the Florida Bay drainage basin. Under natural conditions it is the major source of overland freshwater flow into Northeast Florida Bay. Surface relief in the Taylor Slough headwaters is low. The area is perched at an elevation of approximately 7 feet (2 meters) NGVD. Both Shark River Slough to the north and the rest of Taylor Slough are slightly lower in elevation (Schomer and Drew, 1982).

Canal C-111 Basin. The C-111 canal is the southernmost canal of the C&SF Project, bordering ENP. Construction of this canal by the USCOE was completed in 1967. Canal facilities are presently operated and maintained by the SFWMD. The C-111 drainage basin, as defined by Cooper and Lane (1987a), is approximately 100 square miles. The C-111 Canal borders and drains agricultural areas of south Dade County. Just south of Homestead, the main canal is joined by C-111E and then moves south and south eastward to cross the marl marsh and flow into Manatee Bay at the head of Barnes Sound (**Figure 53**). The C-111 Canal basin is bordered on the west by the East Everglades Area, ENP and the Canal itself. On the east the basin is bordered by the C-103 Basin, C-102 Basin and U.S. 1 right-of-way.

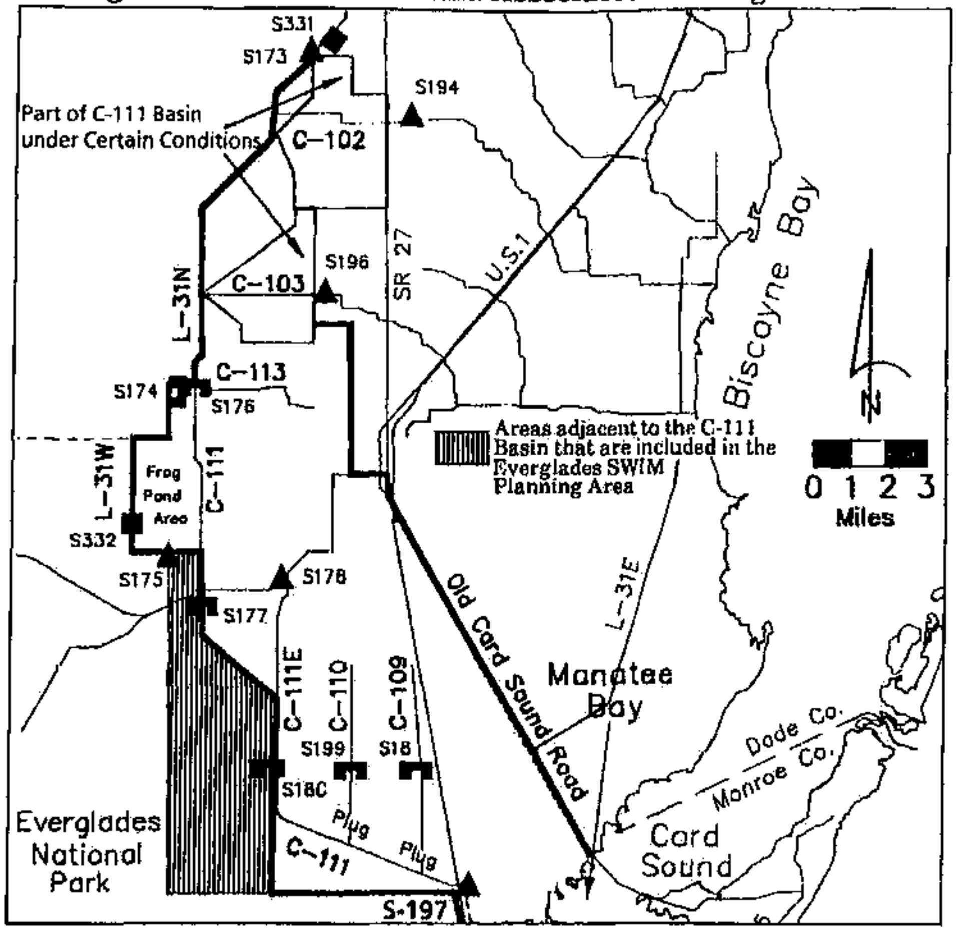
This canal system (also referred to as the Aerojet Canal) was initially constructed as part of the C&SF Project but also contained some modifications to provide access for barges for a proposed rocket engine testing plant. The project includes water control structures S-177, S-18C, S-197, C-109, C-110, L-31N, and C-111 (**Figure 53**). The five operational project canals are the L-31N borrow canal, C-111, C-111E, C-113, and the L-31W borrow canal. The three main functions of these canals are a) to supply water to the eastern panhandle of Everglades National Park and the south Dade area (the *ENP Panhandle* is that portion of Everglades National Park that lies south of C-111 Canal and receives overflow drainage from both the L-31W canal and the C-111 canal during wet periods); b) to prevent saltwater intrusion, and c) to provide flood protection for upstream agriculture interests. The C-111 canal also provides a gravity outlet for stormwater runoff.

Most of southern C-111 subbasin (south of S-176) is comprised of wetlands. These areas are in public ownership by South Florida Water Management District and are managed by the FGFWFC (Metro-Dade Planning Department, 1988). Residential use centers primarily in the Florida City/Homestead region while agricultural zoning is primarily in the Frog Pond Area and to the east. The dominant agricultural crop in the area is winter tomatoes, with some squash, beans, corn, and citrus (Metro-Dade Planning Department, 1978b). During recent years, increased urban development and agricultural activity has occurred in the Homestead/Florida City vicinity (U.S. Army Corps of Engineers, 1988).

The area covered by the C-111 basin is composed of primarily marl soils, mangrove peats or, in the northern portion of the basin, rockland soils (Davis, 1943a; Tabb, 1963). This area is underlain by Miami oolite and forms the end of the Atlantic Coastal Ridge (Davis, 1943a; Parker *et al.*, 1955). The remainder of the southern Everglades is comprised of the "finger glades" or, in places, the "transverse glades" (Davis, 1943a&b; Hoffmeister, 1974). These areas are also underlain by the Biscayne Aquifer and produces water for major wellfields that supply water to southwestern Dade county, Florida City and the Florida Keys.

The SWIM boundary includes the area that lies south of the Frog Pond between the C-111 Canal and ENP. The boundaries of the Everglades SWIM Planning Area, include one additional area outside the boundaries of the C-111 Basin as defined by Cooper and Lane (1987a). This is the area south of Florida City and

Figure 53. C-111 Canal and Associated Drainage Basins



Source: Adapted from Cooper and Lane, 1987a

east of U.S. Highway 1. Historic drainage patterns show that flow occurred to Florida Bay and Barnes Sound through this areas, prior to construction of C-111, U.S. Highway 1 and Henry Flagler's railroad (Parker *et al.*, 1955).

Barnes Sound. Barnes Sound is a semi-enclosed lagoonal estuary that is located between mainland Florida and the upper end of Key Largo (**Figure 50**). Circulation in this sound is generally wind and tide driven (Lee and Rooth, 1972; Lee, 1975). Tidal range within the system is approximately six inches (15 cm), and exchange takes place through Jewfish Creek to the south or Card Sound to the north (Lee, 1975). Average residence times for water in this system are 2.3 months for Card Sound and 3.4 months for Barnes Sound (Lee, 1975). Freshwater historically entered this system as overland sheet flow, aquifer outflow around tree islands and upwelling of fresh water from the aquifer (Harlem, 1979). Currently, freshwater inflow occurs primarily through the C-111 canal. Sheet flow occurred in this part of the Everglades in a southeasterly direction. The existing road bed for U.S. Highway 1 currently has few provisions to allow sheet flow to the southeast (the natural drainage pattern) and so serves as a levee that prevents overland flow of fresh water into Barnes Sound. Although Barnes Sound is located adjacent to Everglades National Park, Crocodile Lake National Wildlife Refuge and Biscayne Bay Aquatic Preserve, it is not included in any formal management plan. Most of the eastern shore of Barnes Sound is within the Crocodile Lake National Wildlife Refuge. Barnes Sound also abuts the western edge of John Pennekamp State Park and provides a buffer for this coral reef system.

Northeast Florida Bay Coastal Swamps and Lagoons. This area includes the downstream freshwater marshes and estuarine systems that extend from the southern edge of Barnes Sound on the East to Madeira Bay in the west and include Little Madeira Bay, Joe Bay, and Long Sound. These areas historically received water from the C-111 basin as overland sheet flow through the ENP Panhandle.

Topography. Natural contours of the East Everglades Area range from a high at Grossman's ridge of over seven feet to near sea level in other portions of the basin (**Figure 54**). The edge of the Atlantic Coastal ridge underlying Miami is found within portions of this basin (see **Figure 51**). Natural contours of the C-111 basin are low and range from five feet and three feet at the most northern portion of the C-111 system, to less than one foot in the fringing wetlands and eventually sea level at the southern terminus of the system (Johnson, 1988). The five-to-three contour lines at the northern portion of the system are narrow and are characterized by stands of exotic vegetation such as *Schinus terebinthifolius* and *Casuarina* sp. (SFWMD, 1990). Generalized contours of the lower C-111 Basin are shown in (**Figure 55**).

Land Use. The SFWMD has collected land use data for the portions of Dade County that lie outside of Everglades National Park. Original data were collected in 1979 and have been updated periodically during the 1980's in response to special projects. The most recent data were collected by the South Florida Regional Planning Council, under contract to the SFWMD in 1987/88.

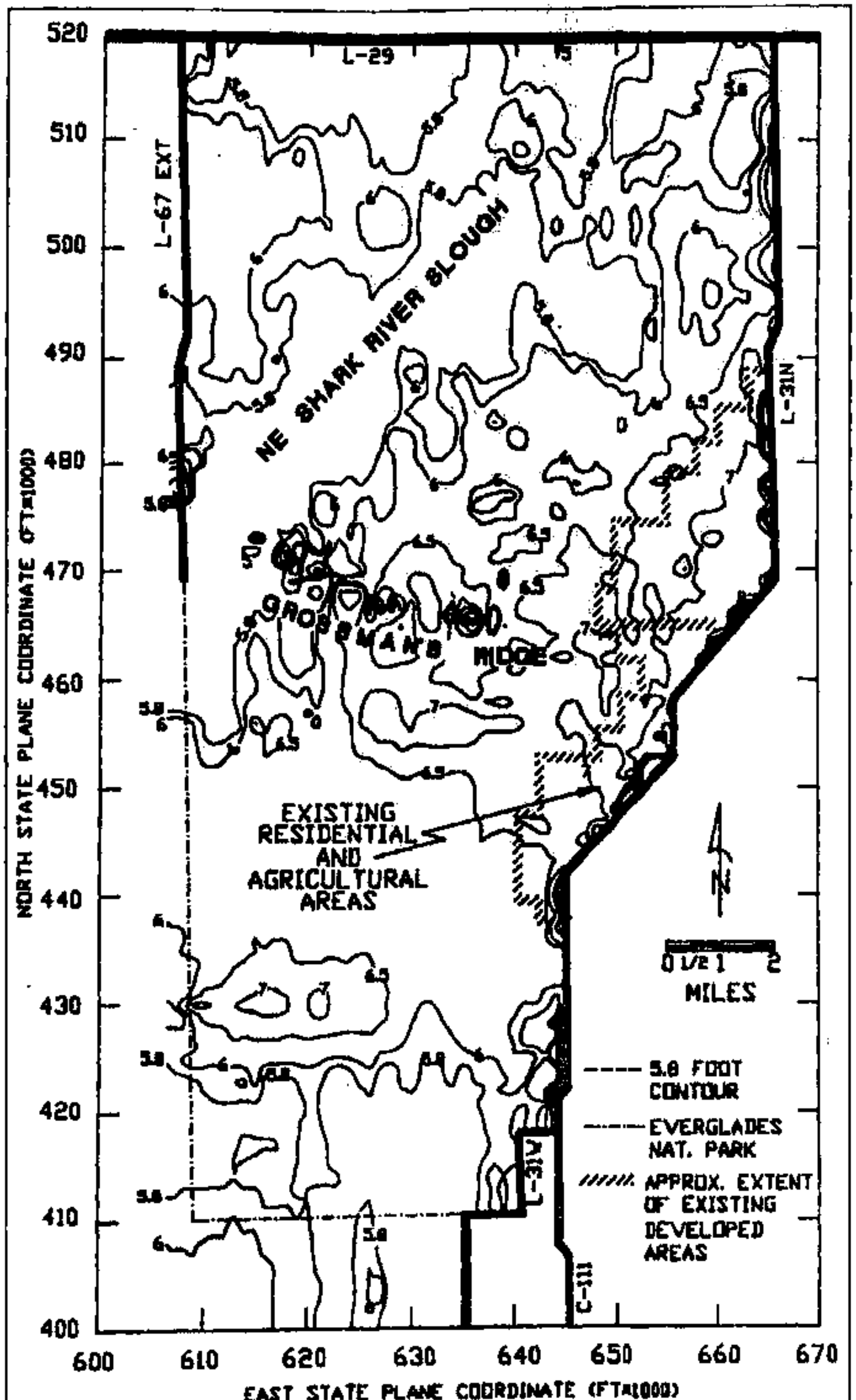
Present Land Use--Everglades National Park Associated Basins. Quantitative estimates of areal coverage of land use categories (Level II/III per the District's Land Use and Land Cover Classification Codes) are not currently available for the entire ENP SWIM Planning Area because vegetation mapping within the ENP has not been completed. However, land use data for areas east of the ENP but within the planning area were obtained from the District's Geographic Sciences Division. The currently available data are summarized by land use code in **Table 61**. Where possible, acreage per Level III code is provided; areas not classified to Level III categories are presented by Level II codes.

ENP Land Use. Present land use patterns within the ENP remain as they have historically. Land uses remain focused on preservation of the natural setting of the Everglades environment and promotion of low impact human uses including education, recreation, and research.

East Everglades. Primary uses of land by man within the East Everglades include residential, recreation, and agriculture. Residential and agricultural activities are restricted to the eastern portion of the area, while recreation activities occur throughout. Of the approximately 242 square miles (63,000 hectares) in the East Everglades/C-111 area, slightly over 8 square miles (2,000 hectares) are categorized as residential, 1 square mile (260 hectares) as commercial, 1 square mile (260 hectares) as public park land, 24 square miles (6,200 hectares) as agriculture. The remaining area is classified as vacant land.

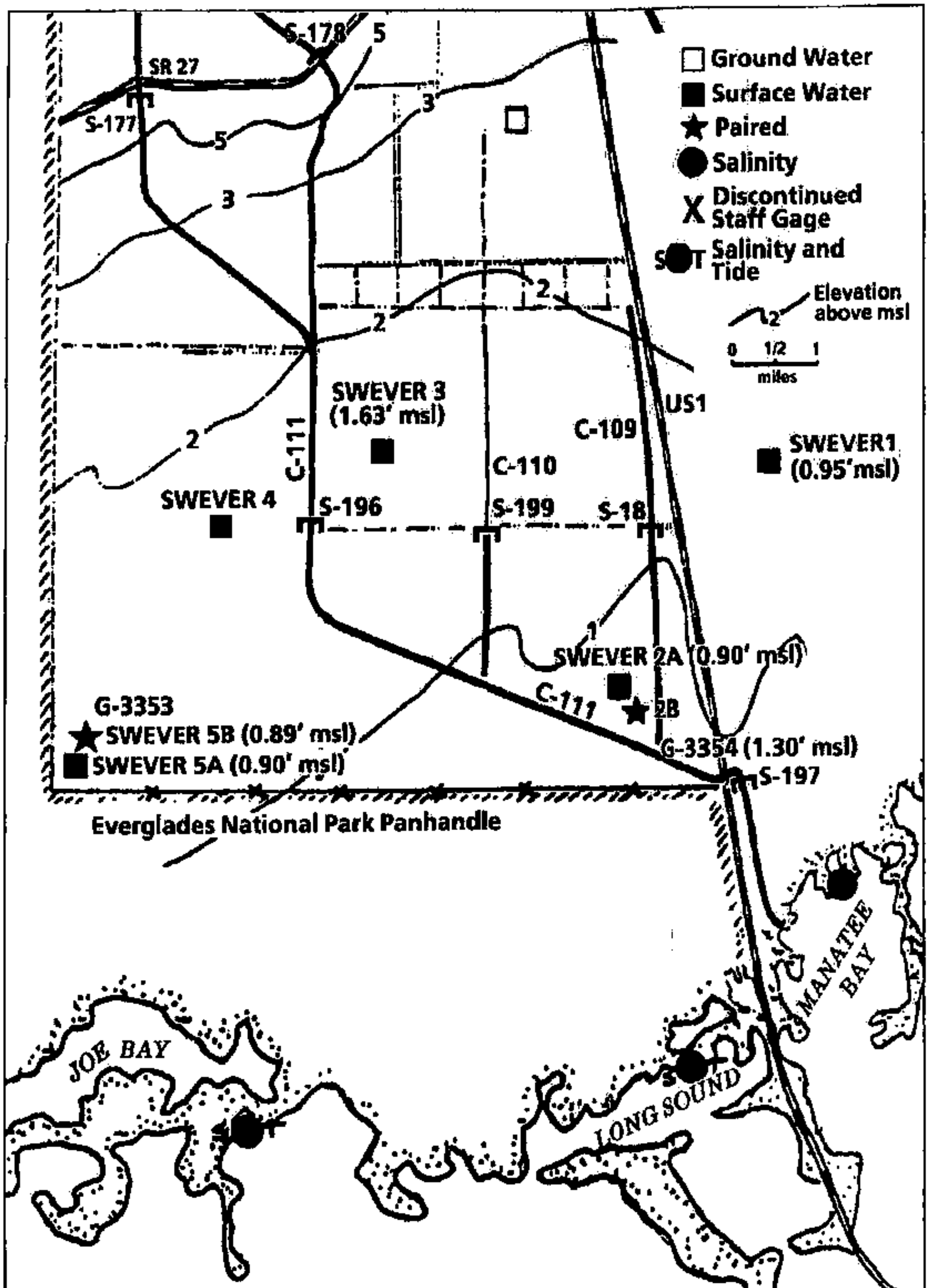
Residential. Residential areas are concentrated in the Richmond Drive and Howard Drive areas. In addition to actual residences, property categorized as residential includes generally small-sized adjacent lands used for crop and farm animal production. The 1980 population estimate for the area was 400-450 persons.

Figure 54. Topography of the East Everglades Area.



Source: Adapted from Neidrauer and Cooper, 1989

Figure 55. Hydrologic Sampling Stations used by SFWMD, Showing Approximate Ground Level Contours in the C-111 Basin.



Source: SFWMD, Unpublished

Table 61. Existing Land Uses in the Everglades SWIM Planning Area, East of ENP.

Level II/III Land Use Code	Description	Acres	Percent of Total
AC	Crop land	24.9	0.02
ACTC	Truck Crops	11,433.2	7.39
AM	Groves, Ornamentals, etc.	4,809.2	3.11
AMCT	Citrus	332.3	0.21
AMTF	Tropical Fruits	664.8	0.43
AP	Pasture	37.1	0.02
APIM	Improved Pasture	87.5	0.06
FE	Coniferous Forested Uplands	96.3	0.06
FEPF	Pine Flatwoods	940.8	0.61
FM	Mixed Forested Uplands	65.9	0.04
FMOF	Old Fields Forested	13,805.9	8.92
FO	Non-Coniferous Forested	269.1	0.17
FOAP	Australian Pine	12.9	0.01
H	Water	854.8	0.55
RG	Rangeland	31.7	0.02
RS	Scrub and Brushland	64.6	0.04
UCMC	Marine Commercial (Marinas)	6.3	0.00
UCSC	Shopping Centers	51.7	0.03
UCSS	Sales and Services	220.1	0.14
UI	Industrial	264.8	0.17
UOGC	Golf Courses	308.6	0.20
UOPK	Parks	815.8	0.53
UORC	Recreational Facilities	88.3	0.06
UOUD	Open and Under Development	26,339.2	17.02
UOUN	Open Urban Undeveloped	1,392.9	0.90
URMF	Multi-family Residential	497.6	0.32
URMH	Mobile Homes	154.9	0.10
URSL	Single Family, Low-Density	44,162.7	28.54
URSM	Single Family, Med-Density	1,534.5	0.99
USED	Educational	63.0	0.04
USMF	Military	50.5	0.03
USRL	Religious	42.2	0.03
UTHW	Major Highways	166.1	0.11
UTRS	Antenna Arrays	383.1	0.25
UTTL	Major Transmission Lines	10.8	0.01
WF	Forested Fresh Wetlands	4,815.3	3.11
WFME	Melaleuca	17.8	0.01
WFMX	Mixed Forested Wetlands	1,679.6	1.09
WN	Non-Forested Fresh Wetlands	38,137.0	24.65

Source: SFWMD, Geographic Sciences Division

The USCOE's Draft General Design Memorandum (GDM) for Canal C-111 (1988) projects moderate growth of agriculture and residential land use in the area. Urban development around Florida City and Homestead is expected to be limited to low or low-medium density, with an upper limit of 13 dwellings units per acre. A greater emphasis on non-row crops, such as tropical fruits, Cuban vegetables, and ornamental plants is expected. Row crops, especially tomatoes, is projected to be concentrated on the rockland soil areas bordering C-111, L-31W and State Road 27.

Agricultural. Dade County is one of the few areas in the country where tropical fruits and vegetables are grown. Production of winter vegetables is also important in this area because of the sub-tropical climate. Agricultural crop production includes winter vegetables, tropical fruits and vegetables, ornamental nurseries, and citrus (Metro-Dade Planning Department, 1978). The Frog Pond is an intensively farmed area within the C-111 Basin (**Figure 61**). In 1984, the District and the ENP agreed to attempt early drainage of this area every fall to allow earlier planting of winter crops and greater crop production, since much of the land in the western sector of the Frog Pond could not be used early in the crop season due to high water levels. In 1988, ENP personnel urged the USCOE to reconsider this policy since it caused an unnatural lowering of the water table within the Park boundaries. The practice of fall drawdowns was discontinued in 1988.

Recent changes in the zoning designations of land in the Frog Pond and vicinity were enacted by the Metro-Dade County Government (Metro-Dade Planning Department, 1988) to better reflect uses of the land at that time. These lands had previously been designated for "Environmental Protection." This designation permits land uses that are compatible with the area's environment and which will not adversely affect the long-term viability of the ecosystems (Metro-Dade Planning Department, 1988). The new designation assigned to these lands is "Agricultural Subarea 1 (East Everglades Agricultural Area)". Permitted activities on lands with this designation include agricultural uses and rural residences at densities of one dwelling unit per 40 acres to one dwelling unit per 20 acres; additional drainage in this area is prohibited (Metro-Dade Planning Department, 1988). This new zoning allows existing agricultural activities in the area to continue, but since drainage will not be improved, it appears to limit activity to seasonal agriculture.

Recreational. Organized and unorganized recreational activities occur in the area. The only publicly-maintained facilities are located at the Chekika State Recreation Area. The recreation area allows low-impact activities such as hiking, camping, and swimming. Unorganized recreational activities occur throughout the area and include hunting, fishing, off-road vehicle operation, soaring (sailplane gliding), skydiving, and hiking.

2. Hydrologic Features.

Construction of the C-111 Canal. The C-111 Canal basin is often considered a subarea of the East Everglades in most planning and land use documents. Because the C-111 basin is considered a distinct water management unit, it is discussed separately in this plan . The C-111 basin lies at the south end of the East Everglades (**Figures 50, 51 and 53**) and includes the Frog Pond. Prior to human activity in the area, the C-111 basin was a wetland that extended north to Florida City and west to Taylor Slough (Metro-Dade Planning Department, 1979). In the early 1900s, human activity was limited to a few farms and some transportation routes (trails). By the 1940s, construction on U.S. 1, extending south from Florida City, was initiated. Construction of C-111 and related structures began in the mid 1960s. At the time when the C-111 surface water control system was designed, planners projected increased agricultural activity, expansion of the semi-urbanized Homestead/Florida City area, and industrial activity to the south. This canal system was initially constructed as part of the C&SF Project, but contained modifications to provide barge access for a proposed rocket engine testing plant (i.e. the Aerojet facility). Although the projected industrial uses never developed, agricultural and urban development expanded into the area. Regular flooding events, caused by normal cycles of precipitation in south Florida, have led to a perceived need for better water control capabilities. The USCOE is evaluating alternative strategies for maintaining flood protection within this basin.

Structural Water Control Features. Although most of L-31N was built by 1952, this canal was built in two stages. L-31N Remainder (the southern portion) was constructed in 1966-67, when C-111 was completed. L-31N canal and L-30 were enlarged and S-331, S-334 and S-335 were constructed as part of the South Dade Conveyance System (SDCS) during the period from 1978 to 1979. The levee system around the southern portion of Water Conservation Area 3 is composed of L-30, L-29, and L-28. Connections to the ENP portions of Shark River Slough are through the four identical S-12 gated culvert structures located between L-67 and L-28.

Connection to the East Everglades section of Northeast Shark River Slough occurs through S-333.

Water Management. In 1963, the completion of the levee system around WCA-3 coincided with a severe regional drought. Subsequent management of WCA-3 as a water storage pool reduced water flow into ENP. Concerns expressed by the National Park Service resulted in the implementation of a congressionally mandated (Public Law 91-282) minimum delivery schedule and a plan to channel water directly to the heart of the slough via a levee and borrow canal. Canal L-67 Extension, was subsequently added in 1967 to promote flow into the ENP portion of the Shark River Slough and serve as a "getaway channel" into the heart of the slough. This arrangement channeled the once 25 mile (40 km) wide sheet flow of the historic Shark River Slough system into less than ten miles (16 km) of the western portion of the area. It was not recognized that it would be necessary for the entire slough to remain intact for Shark River Slough to function correctly. Construction of L-67E exacerbated the existing damage by further isolating Shark River Slough from its historical drainage basin (NPS, 1989; Metro-Dade County, 1988; Goode, 1985).

Currently, hydroperiod in Shark River Slough is controlled by rain events and the District's Rainfall Plan (MacVicar, 1985). The Rainfall Plan was used to recreate aspects of the natural hydrologic system that had been removed by man-made modifications. The rainfall plan provides a means to deliver water to SRS according to a pattern that is correlated to rainfall events (MacVicar and Lin, 1984). This method approximates normal variability in the timing and amount of water and provides for gradual increases and decreases in flow (MacVicar and Lin, 1984; Neidrauer and Cooper, 1989). Flows through Shark Slough under pre-drainage hydrologic conditions are compared to post-drainage flows, prior to the test of the rainfall plan, in **Figure 56**. Because of hydrologic gradients within this area, under some conditions water levels in L-31N serve to regulate water levels in the eastern portions of the EEA (**Figure 57**). Groundwater levels in the Rocky Glades do not respond to discharges at S-333 that have occurred since 1984 (Neidrauer and Cooper, 1989).

History of Agricultural and Urban Development in the East Everglades/ C-111 basins. The dry years that occurred in the early and mid 1960's in conjunction with the completion of the existing system of canals and levees in the 1970's, allowed many areas of the East Everglades and Rocky Glades to be temporarily dry. The perception that these lands were drained resulted in increased pressure for development. Dade County later allowed this area to be parceled into lots smaller than the originally mandated density of one unit per forty acres of land. The county lowered the zoning for the area west of Krome Avenue to one unit per five acres in April 1974 (Goode, 1985).

About this time, it was recognized that alteration of Shark River Slough had created problems with the volume, distribution, and timing of water deliveries to the ENP. Management planning for the East Everglades began in 1978 under provisions of Section 208 of the Federal Water Pollution Control Act. A report entitled, Proposed Management Plan for the East Everglades, was prepared (Dade County, 1980). The county commission, based on the recommendations of this plan, declared the East Everglades an area of Critical Environmental Concern in January, 1981 and passed the East Everglades Zoning Overlay Ordinance in October, 1981. This ordinance reduced the zoning densities of most of the area from one unit per five acres to one unit per forty acres. However, the ordinance also provided that land use of one unit per five acres would be allowed "...in that portion of Management Area 1 which

Figure 56. Pre-Drainage and Post-Drainage Flow in Shark River Slough.

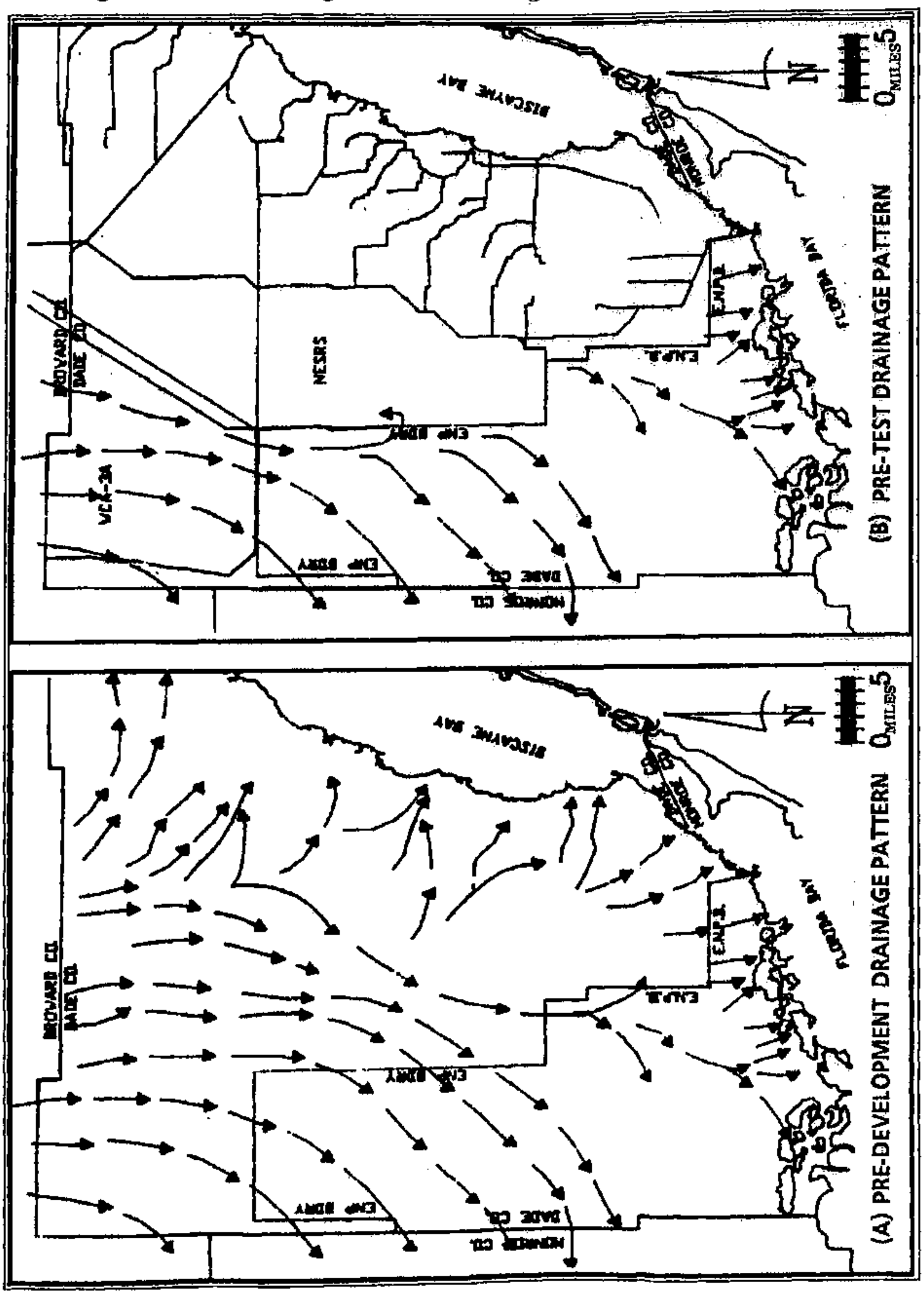
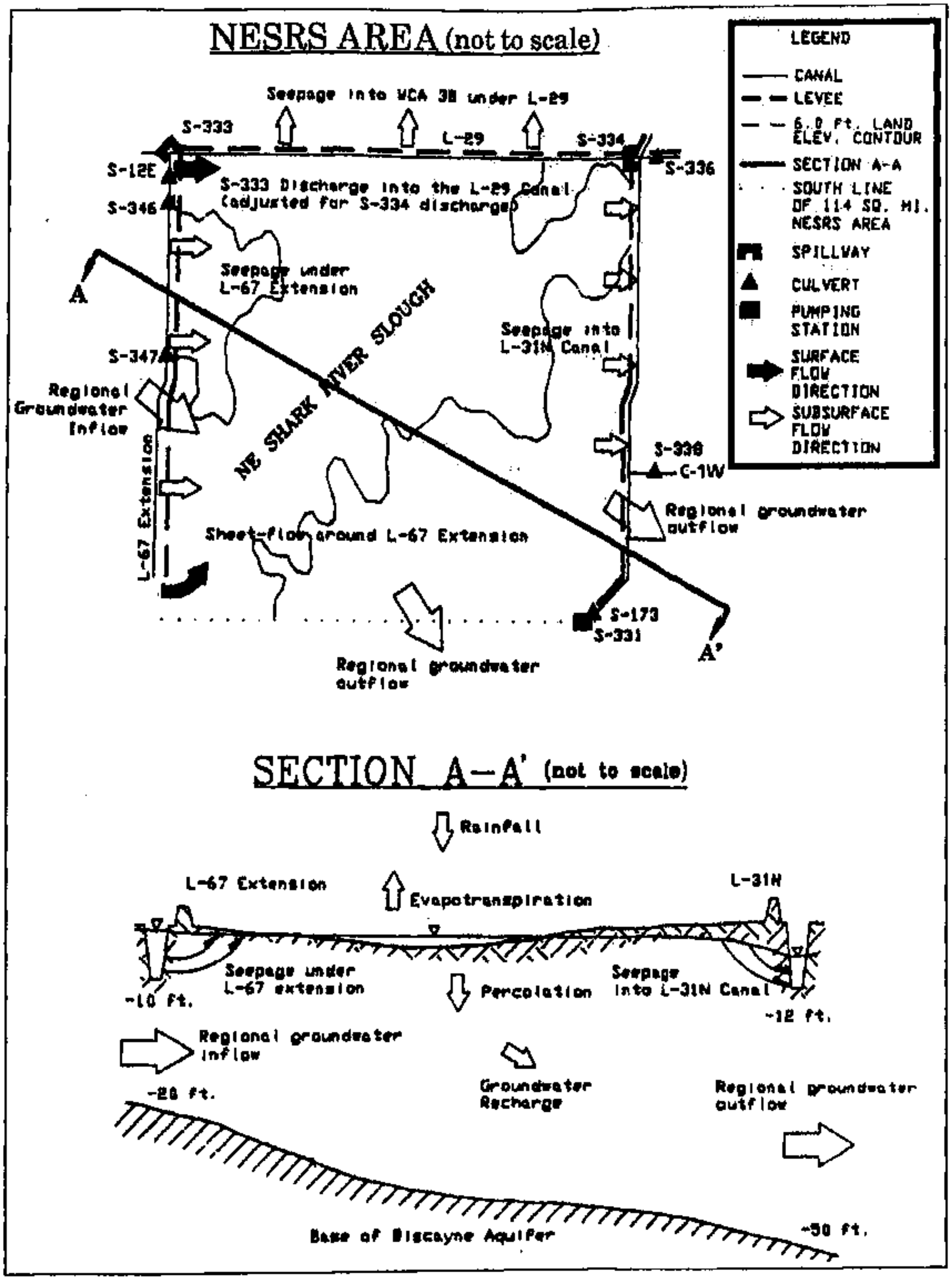


Figure 57. L-31N Regulation of Water Levels in the East Everglades Area.



had established residential character as of January 14, 1981, provided that positive drainage flood control facilities are available to protect the area from a one in ten year flood event" (Goode, 1985).

During the period from August 17 to 22, 1981 record rainfall occurred in South Dade County due to the passage of Tropical Storm Dennis and resulted in standing waters in the East Everglades. The West Dade Acres Homeowners Association was formed to secure the interests of landowners in this area (Goode, 1985). Governor Graham formed a special task force at that time to investigate the causes of flooding in the East Everglades and suggest solutions to these problems. The published recommendations from this task force included the formation of a special task group to seek long-term solutions to the problems of the East Everglades. On February 7, 1984, Governor Graham established the ENP-East Everglades Resource Planning and Management Committee under Chapter 380 of the Florida Statutes. The work of this committee coincided with the Governor's Save Our Everglades Program and has provided the basis for the recommendation that the rest of the East Everglades should be acquired for public ownership. This is seen as the best means to preserve and restore historic headwaters of major sections of ENP. In 1987, recommendations from this committee were to await the review of the research and evaluation in progress by the Southern Everglades Technical Advisory Committee (SETAC) . Currently, most of the programs are complete, but the status of both the Governor's 380 Committee and SETAC are presently unknown.

Prior Water Management Projects and Activities.

South Dade County Survey Review Report and GDM. The first overall plan for flood protection and water control for southern Dade County was presented by the United States Army, Corps of Engineers (USCOE) in the Survey Review Report on the Central and Southern Florida Project, South Dade County (USCOE, 1961). The L-31W Canal system was not included as part of this plan. The remaining major flood control and water supply facilities for southern Dade County were addressed in the General Design Memorandum (GDM), South Dade County (USCOE, 1963). The L-31W Canal and control structures S-174 and S-175 were added to the project as part of the memorandum following recommendations by the NPS and the United States Fish and Wildlife Service (USFWS).

Construction of the canals began in the early 1960's as part of a drainage plan for south Dade County. By 1965, the C-1, C-2, C-100, C-102, C-103, and C-111 canals had been constructed and control structures were added to all new and existing canals to reduce salt water intrusion, and to retard overdrainage of ground water. In 1966, construction began on the remainder of the L-31N Canal. Structures S-173, S-176, and S-177 were added to control flows south into the C-111 Canal. At the same time, several older canals (C-1, C-102, and C-103) were extended west to the L-31N Canal to provide improved flood protection and water supply to these basins.

South Dade Conveyance System. The need for more fresh water in Taylor Slough and the downstream areas of Florida Bay prompted Congress to authorize construction of the South Dade Conveyance System (SDCS) as part of the Flood Control Act of 1968. Construction of the L-31W Canal and structures S-174 and S-175 began in 1968 and were completed in early 1970's. The remainder of the project was constructed between 1978 and 1980 and primarily consisted of enlarging existing culverts, borrow canals, and structures. The SDCS facilities include S-151, S-337, S-335, S-336, S-334, S-333, S-338, S-331, S-332, C-304, L-30, L-29, L-31N, and L-31W (**Figure 43**). This system of canals, structures and pump stations was superimposed on those that already existed above the C-111 system for the purposes of conveying additional water supplies for the ENP and for agricultural and urban development along the lower east coast (Cooper and Lane, 1987a). The SDCS was designed to provide 55,000 acre feet per year of supplemental water to the eastern portion of the ENP to meet the congressionally- mandated minimum delivery schedule.

Problems within the extreme southern part of Dade County, generally result from the combined impacts of the SDCS, other flood control project facilities, and the C-111 system. The completion of the SDCS enlarged the capacity of the existing northern portion of canal system above C-111 without adequate provisions to accommodate the additional flow of water in the southern end of the system. Construction of the SDCS also facilitated agricultural and residential development of adjacent wetlands during dry years. This resulted in increased flooding of agricultural lands during wet years and subsequent requests for additional drainage and flood protection.

C-111 Canal GDM. When initial construction of the C-111 Canal was completed, the terminus of this canal was plugged with a gated, structure with three culverts (S-197) to prevent saltwater intrusion (Cooper and Lane, 1987a). Plans at this time were to periodically remove the structure to allow navigational access to the Aerojet properties. This never occurred because the Aerojet property has never been developed for industrial use. A more final solution, an operable structure in the terminus of this system, has never been constructed. Changes in economic growth for this region and shifting priorities made the completion of the planned extensive system of canals, which had once been proposed, no longer practical. The original proposed C-111 Canal network was never completed.

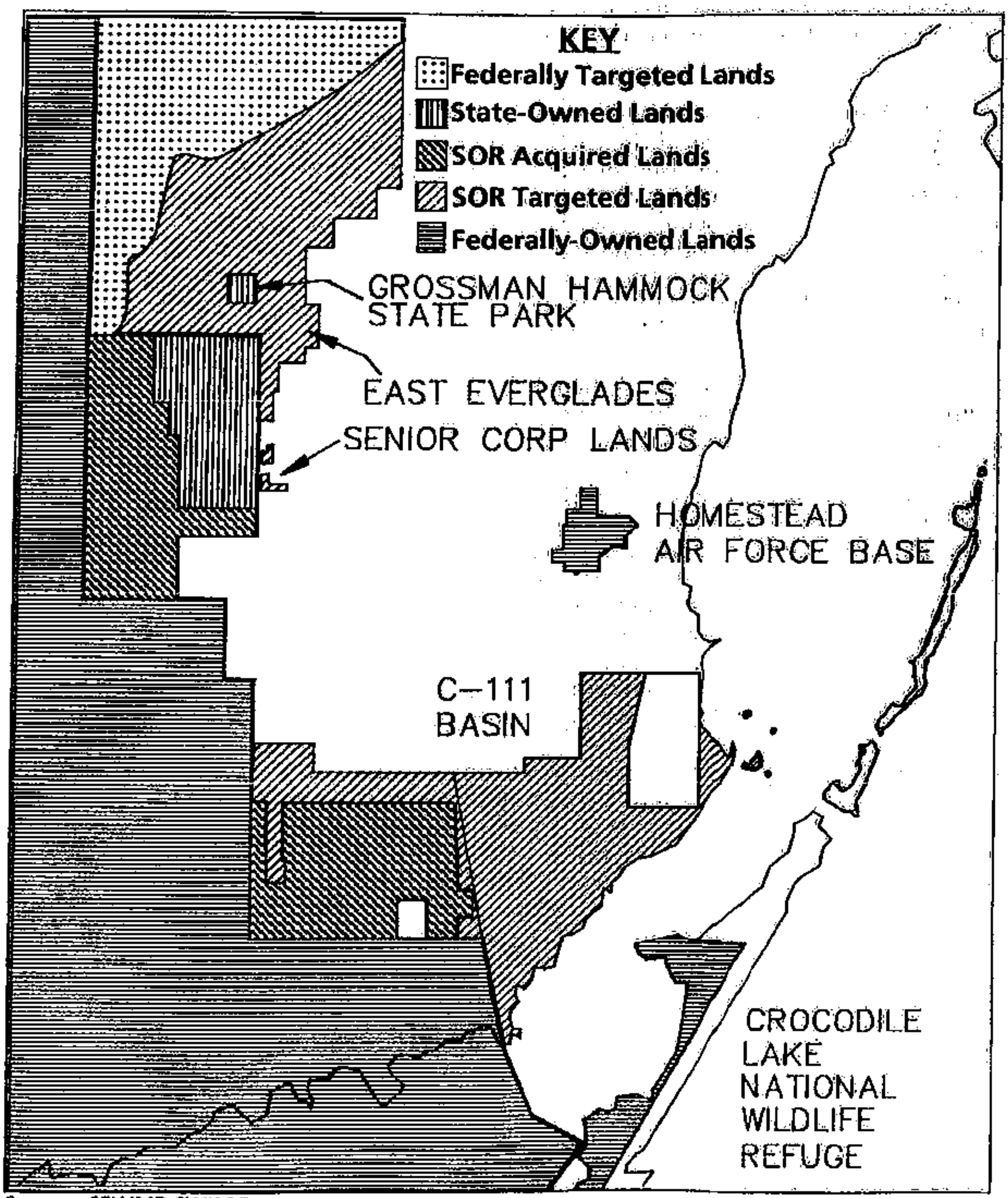
Agribusiness and developers in this region of south Dade County have continually requested that increased flood protection be provided in the East Everglades and C-111 Canal basin. These requests have raised concerns among the National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), national environmental groups, and local residents outside the basin. Interests opposing the increased flood protection for this area generally fear that damage will occur to ENP, remaining sensitive wetlands in these areas, as well as biological impacts to coastal estuaries that serve as receiving systems for this drainage.

The USCOE is preparing a Draft General Design Memorandum (GDM) to complete the C-111 system by adding a controllable structure at the terminus of the canal, some structural changes to accommodate added flood protection and improved water flow to Taylor Slough and Northeast Florida Bay. This plan is currently under agency review and expected to be modified and made available to the public in 1992.

Regional Water Management Issues. Portions of the East Everglades and C-111 basins comprise the largest remaining undeveloped wetland areas in Dade County. This basin lies adjacent to Everglades National Park and drains into the sensitive estuarine systems of Northeast Florida Bay, Manatee Bay, and Barnes Sound. Large portions of this region are currently in public ownership and more area is under consideration for purchase. Public ownership lands and lands under consideration for purchase are shown in **Figure 58.**

Issues within this region include extensive farming interests, shifting of crop type from seasonal vegetable crops to year round crops, water supply, flood control, rock plowing, urban development, restoration of overland flow to Shark Slough,

Figure 58. Publicly-Owned Lands and Areas Targeted for Acquisition under the Save Our Rivers (SOR) Program within the C-111 Study Area.



Source: SFWMD SWIM Program

restoration of overland flow to northeast Florida Bay, widening of U.S. Highway 1, and periods of excess discharge of freshwater to Manatee Bay alternating with extended periods of low or no flow.

Development and Land Use Impacts. Agricultural land uses within this region have continued to shift from seasonal crops such as tomatoes and vegetables to year-round crops and plants such as citrus, tropical fruit, and ornamental nurseries that require more intensive water management (Metro-Dade, 1989). Eastern agricultural lands continue to be converted for development, which forces farming activities further westward into wetland areas that require rock plowing and additional flood protection. Rock plowing is the practice of breaking up and crushing the native limestone pinnacle rock formations until they become a coarse, aggregate gravel that is then disked, furrowed and farmed. This type of agriculture often requires intensive use of water, pesticides, herbicides, and fertilizer (Baker, 1988).

Increased demands for development in the Florida Keys have reinstated plans to consider widening of the U.S. 1 Highway corridor to accommodate more traffic through south Dade County to the Florida Keys. This widening, if not properly designed, may further impact freshwater flows and water quality reaching Barnes Sound and Northeast Florida Bay.

Altered Hydroperiods. Historical water management practices within portions of this region have resulted in over drainage and shortened hydroperiods for these marshes. In other areas, ponding and prolonged hydroperiods occur in marshes that are impounded by levees and inactive canals. In addition, water distribution and flow patterns have been altered, preventing natural sheet flow conditions which affect marsh hydroperiod. Drainage of upland basins have resulted in large periodic discharges of freshwater into Manatee Bay, Barnes Sound, and adjacent estuarine areas during extreme storm events, impacting marine biota. Extended periods of low or no flow conditions during the dry season impact the salinity balance of these estuarine systems. ENP, along with other federal and state agencies and environmental interests have identified the need to restore more natural patterns of overland flow to Northeast Florida Bay (Johnson *et al*, 1988).

Impacts of Canal Discharges. The C-111 canal is the major source of freshwater currently entering Barnes Sound and Northeast Florida Bay. Water enters this system through either the structure at S-197 or through a series of gaps in the south spoil bank of the canal along the reach from S-18C to U.S. Highway 1. Most water flow into Northeast Florida Bay from C-111 occurs as overland flow through these gaps (SFWMD, 1990). Barnes Sound has had problems resulting from alternating periods of hypersalinity and extreme freshwater discharges. Under low rainfall and normal operating conditions, little overland or canal flow of freshwater goes into Barnes Sound. As a result, this lagoon periodically experiences hypersaline conditions during the dry season (Lee, 1975; SFWMD, 1990). Barnes Sound can provide a nursery for many fish and invertebrate species (Bader and Roessler, 1972; Smith *et al.*, 1950; Roman *et al.*, 1983). However, hypersaline conditions in this region may severely restrict its productivity as a nursery and breeding habitat (Zillioux, 1978).

During periods when flood waters are moved through the system, freshwater inflows to these eastern areas can alter the salinity balance of the system. Because residence times are long for these lagoon systems, large discharges may result in the formation of an isolated mass of freshwater that does not readily mix with the surrounding high salinity waters (Lee, 1975; ChinFatt and Wang, 1987).

When upstream flood conditions in the C-111 canal necessitate removal of the earthen dam or plug adjacent to the culvert structure (S-197), these problems become acute and severe. Once the earthen dam structure at S-197 is removed, it can only be replaced after flow through the canal decreases to the point where water can be held upstream at S-18C. Flow must be stopped to allow the earth works to be replaced without being washed into the estuary. Placement of a water control structure at S-197 would allow control of the rate and volume of water discharged to Barnes Sound.

Present Water Management System. The five operational canals in the C-111 basin are; C-111, C-111E, C-113, L-31W, and the L-31N canal. These canals have the following three functions (Cooper and Lane, 1987):

* To provide drainage and protection for the C-111 Basin
* To supply water to the C-111, C-102, C-103 Basins, and to ENP (i.e. Taylor Slough and the panhandle of the ENP)
* To maintain ground water table elevations sufficient to prevent saltwater intrusion.

The twelve Project control structures in the C-111 Basin are S-331, S-173, S-194, S-196, S-176, S-177, S-178, S-174, S-332, S-175, S-177, S-178, S-18C, and S-197 **(Figures 51 and 53)**.

Operation of the System. The L-31N borrow canal runs in a north south direction and serves to deliver water to ENP, the C-111 Basin and Dade County as part of the South Dade Conveyance System (SDCS). L-31N enters the C-111 basin at structure S-173 just north of Richmond Drive and discharges to the C-111 at S-176 and to L-31W an auxiliary structure for the ENP at Structure S-174. Flow in the Canal is to the south. The L-31W Canal is used to make deliveries to Taylor Slough through S-332 and S-175. Water is discharged to the panhandle of the ENP through a series of gaps in the south berm of C-111 between S-18C and S-197. Water overflows through these 55 openings in the canal berm across a five mile wide segment of marsh. The gaps are each 100 ft (30.5 m) wide through the south spoil bank (**Figure 55**).

Water is delivered to the Planning Area from canal L-31N and structure S-332 and into the eastern panhandle of the park through cutouts in the southern levee along C-111. C-111 actually begins at structure S-176 and flows south through the regulatory structures S-175, S-177 and S-18C. Structure S-18C is the last actual regulatory structure in the system. Once water has moved though this structure it can move through S-197 at a rate up to 550 cfs (15.5 m^3/s), although the large majority of the flow passes through the gaps into the panhandle of the ENP (Cooper and Lane, 1987a). Flow through S-197 is through the three gated culverts at the terminus of the system in the earthen plug structure on Manatee Bay.

Unused canals C-110 and C-109 run north to south and are inactive in the system (**Figure 55**). Both canals were partially completed prior to the decision to stop construction on the southern half of the system. Although both canals have structures they are not functional and earthen plugs have been placed at their confluence with the C-111. Neither canal has an open channel or a controlled connection with C-111. Due to the north-south orientation of these canals and the general southeast surface water flow pattern of this area the canals serve as passive impoundments and and their levees impede sheet flow across the marsh (Ogden and Johnson, 1989).

Flow is passed through S-18C once the stage at this structure reaches 2.3 ft (70 cm) NGVD. Once water is moved passed this structure it can be dispersed four ways:

1. As controlled flow through the culvert structures in S-197 to Manatee Bay and Barnes Sound.
2. As overland flow through the 55 gaps in the spoil bank on the south side if C-111, towards ENP panhandle and northeast Florida Bay.
3. As flow northward through the nine culverts in the north C-111 when the stage exceeds 2.0 ft (61 cm) NGVD (control board setting) and a lower water level occurs in the marsh to the north.
4. As groundwater recharge to the limestone aquifer (SFWMD, 1990).

Impacts of Water Management Activities. Operation of project facilities has had observable effects on water conditions within the system. Impacts on specific areas are noted in the following sections.

Taylor Slough. Groundwater records suggest that changes have occurred in the water table of the Taylor Slough drainage basin as a result of the levee and canal construction in the 1960's. Specifically, these records suggest less seasonal variability and a lower overall seasonal minimum (Tabb, 1967; Schneider and Waller, 1980). In 1970, PL 91-282 was passed which made appropriations for the 1948 Flood Control Act authorizations and required part of the money to be used for accelerated construction of L-70, C-308, C-119W and S-326. Also, when these works are completed, mandated 315, 000 acre-feet annually as set forth in the National Park Service letter of October 20, 1967. Before the 1979 agreement between the National Park Service and the U.S. Army Corps of Engineers that set up the arrangement to pump an additional 37,000 acre-feet into the upper Taylor Slough per year, these areas were effectively dry for much of any given year.

C-111 Basin. Impacts on this system are primarily the result of the intensive agriculture in the northern portion of the C-111 system, water management of the region and urban development adjacent to and in historic wetland slough areas. Impacts resulting from these situations include the following: pesticides and contaminants in surface waters, sediments and soils; altered hydroperiod, timing, and flow for the region; lowered water table; the encroachment of exotic plant species due to farming and artificially dry conditions; and impacts on the downstream estuarine systems due to artificially altered water flow.

Drainage patterns at the northeastern end of the study area, in the Card/Barnes Sound drainage basin, have been altered significantly by drainage and development. Prior to the construction of roadway levees, local drainage canals, and the construction of the C-111 canal in 1967, bedrock contours and natural Everglades floodway channels through the coastal ridge provided most of the directional flow into this basin.

Since 1981 the terminal outflow structure of the C-111 canal system, the plug at S-197, has been removed on five separate occasions to alleviate flood conditions for this basin (**Table 62**). This has resulted in damage to downstream estuarine receiving system (Barnes Sound and northeast Florida Bay). These discharges have had severe impacts on the seagrass and hard-bottom marine communities, and has impacted the marine fisheries resources of the area (SFWMD,1990). Moreover, loss of historic freshwater sheet flow characteristics as a result of canal construction is

Table 62. Removal of the S-197 Structure.

Date of Removal of S-197	Date of Replacement of S-197	Length of Time Prior to Replacement of the Structure
August 18, 1981	August 28, 1981	10 days
September 27, 1981	October 5, 1981	8 days
June 3, 1982	June 5, 1982	2 days
July 23, 1985	July 24, 1985	1 day
August 15, 1988	August 23, 1988	8 days

Source: SFWMD Operational Data

thought to have affected the overall productivity of this estuarine system by preventing the gradual release of particulate nutrients into coastal waters (SFWMD, 1990).

The current water management system results in little overland flow to the downstream estuary at Barnes Sound. Barnes Sound salinities would normally be modified by exchange with Northeast Florida Bay, exchange with the Ocean, or by overland flow of freshwater. Barnes Sound has extremely restricted natural circulation that is primarily wind driven and may have residence times of up to one year depending on wind speed and direction (Lee, 1975; Lee and Rooth, 1972). Ocean exchange takes place over long periods of time and so was not as as rapid as overland flow or exchange with northeast Florida Bay. Barnes Sound salinities are naturally affected by exchange with northeast Florida Bay and, through Card Sound, the ocean (Lee, 1975). Salinities between 33-40 ppt were reported during the wet season and salinities from 39-46 ppt have been reported during the dry season (Lee, 1975).

Water exchange by systems other than the ocean have been modified and reduced since Flagler's railroad was built and the C-111 system was created. Barnes Sound and northeast Florida Bay were once more interconnected than they are currently (Evink, 1981). Historically there were more interconnections between Barnes Sound and Northeast Florida Bay that were filled during the construction of Flagler's railroad (Evink, 1981). Addition of the C-111 canal and the roadbed for U.S. Highway 1 removed overland flow by channelizing water and impounding overland sheet flow. The U.S. Highway 1 roadbed serves as a levee to this overland flow. Salinity data collected from the northeast corner of Long Sound suggests that waters released from the upstream gaps in C-111 ultimately flow to the southeast following the marsh topography and are directed south to eastern Long Sound (SFWMD,1990).

Manatee Bay and Barnes Sound, both estuarine water bodies with constricted exchanges with adjacent water bodies, have a precipitous drop in salinity levels at the time of release. The result has been temporary removal of some estuarine communities, particularly turtle grass and mangrove prop-root communities as well as associated animal species (SFWMD,1990). Tabb (1967) found that, if ground water levels at the Homestead well increased to 1.8 m (6 ft) above mean sea level, salinity in Florida Bay declined to 10 to 15 ppt. He suggested that this increase represented an overflow phase pushing down-gradient into Florida Bay. Due to the impedance of this overland flow and channelization of water, estuarine conditions have not been allowed to "naturally" fluctuate in northeast Florida Bay and are altered in Manatee Bay and Barnes Sound. The problem of large episodic releases of freshwater is made more complicated by the potential presence of suspended sediments containing bound contaminants from the urban and agricultural areas of south Dade County.

Minimum Delivery Schedule and Operation of the SDCS. Concern for the declining resources and integrity of the Park led to the decision to implement minimum deliveries to the Park in the late 1960's. These deliveries were mandated by Congress in Public Law (PL) 91-282 and were based on two studies in the 1960's to determine flow volumes necessary for the Park. The two studies (Dunn, 1961 and Hartwell *et al.*, 1963) concentrated primarily on the requirements of Shark River Slough as the major inflow source of water for the region. These studies however did not address flows from the Big Cypress Basin and particularly flow necessary for Taylor Slough and the Panhandle portion of the Park (Wagner and Rosendahl, 1987).

Public Law 91-282 established a minimum delivery schedule for Taylor Slough based on the work of Dunn (1961). An estimate of locally-derived flow was computed based upon comparisons of a year of USGS flow records including the flow sections identified as "Taylor Slough near Homestead" and flow to Shark River Slough "Tamiami culverts 40-62". Spill over from Shark River Slough was estimated and added to this flow to arrive at an annual flow of 55,000 acre feet. The median discharge value (38,000 acre feet) was recommended as the minimum requirement. Ultimately, a value of 37,000 acre feet appeared in PL 91-282 as the minimum annual requirement for Taylor Slough. The minimum delivery schedule for the ENP's eastern panhandle designated in PL 91-282 was 18,000 acre feet.

Delivery schedule and operation of the system are complicated by the fact that L-31 acts to conduct excess water south through the C-111 system. The net result has been an increase in the volume of water flowing down the C-111 system since 1981 (**Figure 59**). The increase in annual flow at the southern end of the system is directly related to changes in the upper basin, north of S-176, since 1980. Two significant water management issues drive the hydrologic behavior of the system. First, upper basin design changes have resulted in an increase in the annual volume of water that flows to the lower end of the system. Second, the design of the coastal water control structure, S-197, provides limited management flexibility which leads to unacceptable environmental damage during major storm events. The implementation of the rainfall plan showed that, in fact, the L-31N acts to draw down water levels and control groundwater in the Rocky Glades area of the East Everglades (Neidrauer and Cooper, 1989). It is therefore possible to mediate ground and surface water levels in the developed area of the East Everglades by pumping more water down L-31N.

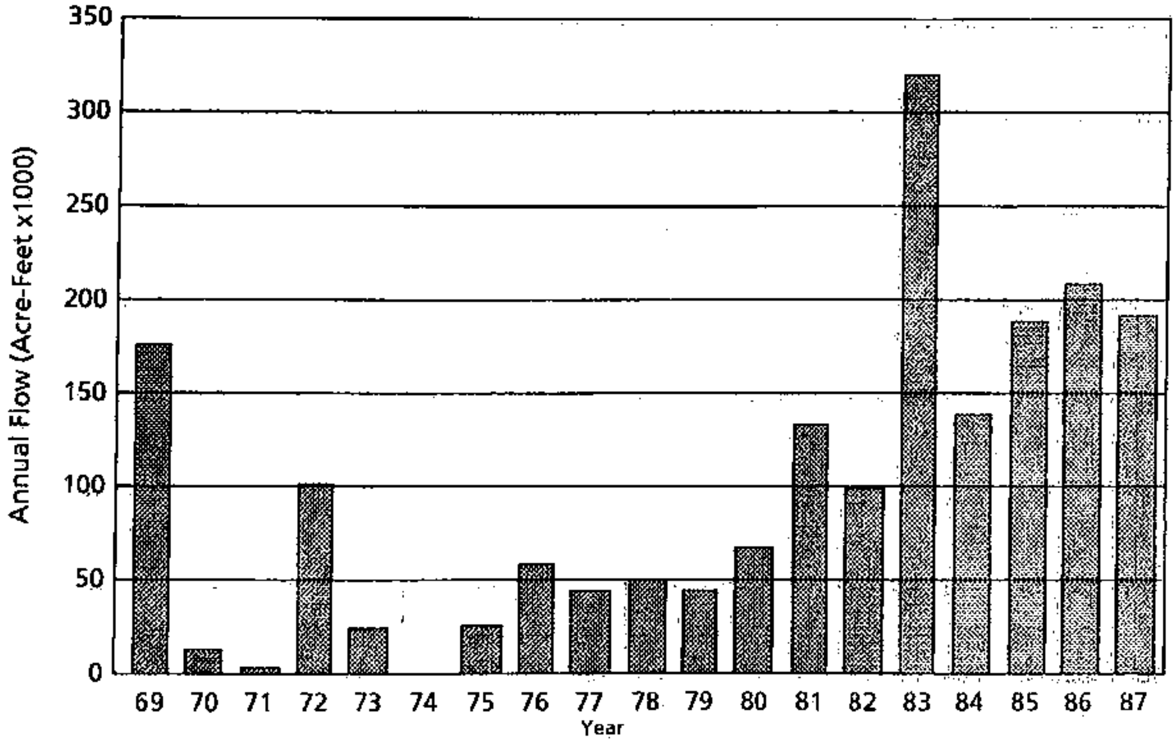
Since 1981, there has been an increase in the volume of water passing downstream to the southern portion of the system (**Table 63**). **Figure 60** is a double mass plot of rainfall recorded upstream of C-111 (Homestead) versus flow recorded downstream through S-18C reduced to inches of runoff from the basin. This technique removes most of the influence of rainfall variability and highlights changes in the basic rainfall/runoff relationship of the watershed. Changes in slope of the relationship indicate physical changes in the system that influence the hydrologic response of the system. Two noticeable changes in slope are evident. The first, occurring in the 1979-1980 period, is evidence of the canal enlargement upstream of S-176 associated with the construction of the South Dade Conveyance System. The enlarged canal intercepts additional seepage which eventually flows through C-111. During this period the deficiency in the size of S-176 was recognized and the District began to make changes in the operation of the structure to

Table 63. Annual Rainfall and Flow for S-18C.

Year	S-18C Flow (ac-ft x 1000)	S-18C rainfall (inches)
1977	44.96	45.55
1978	51.09	58.84
1979	44.17	43.51
1980	67.31	44.70
1981	132.93	44.00
1982	99.49	47.51
1983	319.89	53.21
1984	139.41	33.33
1985	189.23	49.70
1986	212.45	33.91
1987	191.51	39.56

Source: SFWMD Operational Data

Figure 59. Annual Flow through C-111 at S-18C since 1969 (Thousands of Acre-Feet).

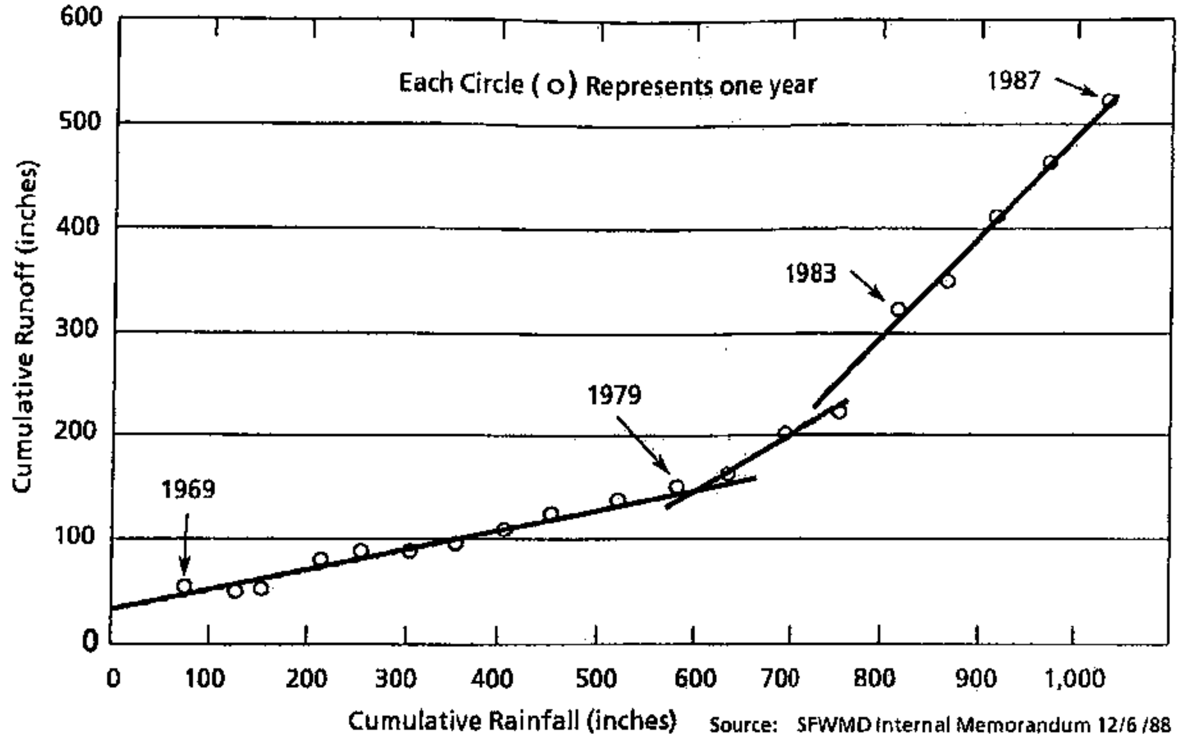


Source: SFWMD, 1990, in press

compensate for the lack of sufficient structural capacity. These changes resulted in lower static water elevations north of S-176 and increased flow through the structure.

Mean flow for S-18C prior to 1981 was 51.88 X 10^3 acre feet (standard deviation= 10.7 X 10^3 acre feet) however for the years 1981-1987 mean flow was 183.56 X 10^3 acre feet. This represents a three-fold increase in flow for the southern half of the system. Rainfall however, averaged 44.89 inches (114 cm)(sd=7.61 inches) and was consistent throughout the period--all values were within 2 standard deviations of the mean. These data graphically represent the magnitude of increase in flow down the C-111 system from 1970-1987 (**Figures 59 and 60**).

Figure 60. Double Mass Curve of Rainfall at Homestead Versus runoff Through S-18C.



Impacts on Coastal Forests and Estuarine Systems. During the summer wet season the stunted (or dwarf) mangrove forest and marshes north of Long Sound and Joe Bay experience freshwater conditions (SFWMD, 1990). These conditions alternate with brackish or saline conditions with salinities from 3-28 ppt in the marsh itself. Chloride values used as tracer measurements indicate the influence of C-111 canal waters on the marsh and mangrove areas directly south of the cutouts in the C-111 canal bank (SFWMD, 1990). Water quality data collected by the SFWMD (1990) suggests that water moves out of the canal through the gaps and follows the natural land surface elevations to the southeast, eventually ponding up against the road bed along U.S. 1 and flowing south to the eastern portion of Long Sound.

The C-111 Canal affects the southeasterly sheet flow of water in the area east of Taylor Slough. The canal concentrates water flow that once spread and flowed into Joe Bay, Trout Cove, Long Sound, Manatee Bay, Barnes Sound, Card Sound, and their adjoining water bodies and delivers that flow through the gaps in the dike lining the south bank of the C-111 Canal into the panhandle of ENP. Occasionally, excess water is discharged directly into Manatee Bay and Barnes Sound. Construction of the canal and the S-18C control structure are assumed to have dampened the C-111 marsh hydroperiod. Groundwater levels exhibit less variability; however, the seasonal lows are lower and the peak average highs are dampened by the automatic opening of the structure when the upstream stage reaches 2.3 ft (Schomer and Drew, 1982).

Montague *et al.* (1989) studied the current conditions south of the C-111 Canal in anticipation of modifications in the freshwater delivery in the area. They selected three tributary-to-bay systems (to the west, Taylor River to Madeira Bay; central, Snook Creek to Joe Bay to Trout Cove; to the east, Highway Creek to Long Sound to Little Blackwater Sound) to investigate current water quality and benthic habitat conditions. The eastern system exhibited a lower salinity range as a result of upstream inflows of freshwater. Differences in the degree of salinity fluctuations were greatest in the western system due to lower discharge of freshwater in that system. The temporary plug and culvert (S-197) on the C-111 Canal east of U.S. Highway 1 accounts for the greater flow in the eastern system by blocking an apparently historical water flow to the east. The water now accumulates and flows down Highway Creek.

Hydrologic Management Recommendations. The District, the USCOE and other agencies that have studied the C-111 basin and East Everglades have developed a number of recommendations concerning management of the hydrology of this system. In most cases these are reflected in ongoing planning and construction efforts to make structural or operational changes to the system.

C-111 Canal GDM. The purpose of the USCOE's Canal 111 GDM is to complete an authorized plan of improvement for flood control, environmental enhancement, and water management in the C-111 Basin. Specific objectives are to:

1. Develop a plan that would provide the flood protection authorized for the South Dade County area.
2. Restore sheet flow, in so far as possible, to the marsh adjacent to C-111 and to northeast Florida Bay via ENP.
3. Reduce large freshwater flows to Barnes Sound.
4. Protect, preserve, or minimize impacts on significant historic or cultural resources.

According to the 1988 acre feet Canal 111 GDM, several problems have been attributed to the change in flows caused by C-111. These problems include:

1. *Alteration of wetlands within the basin.* The canal has drained surface water from the adjacent marshes reducing hydroperiods (depth and duration of flooding), in turn affecting the productivity and habitat value of the marshes. In other areas, ponding has occurred where flow is impeded by levees, as where C-111 intersects U.S. Highway 1. Additionally, there is poor distribution of flow over the marshlands in the eastern panhandle of ENP to the northeast of Florida Bay.
2. *Reduction in estuarine productivity.* Discharge of flood waters to Barnes Sound via C-111 and removal of S-197 causes rapid decreases in salinity. Florida Bay and Barnes Sound have been described as a nutrient limited system, and the loss of historical overland flow of flood waters deprives the estuaries of a flush of nutrients that would otherwise accompany large storm events.
3. *Alteration of the salinity balance of Florida Bay.* There are unnatural cycles of both reduced and hypersalinity as the result of water management practices and control within the C-111 Basin.

A storm in August 1988, which required the removal of the earthen dam at S-197 to allow flood control within the C-111 Basin, heightened concern over the environmental consequences of water management practices within the basin. This discharge of a large volume of fresh water caused significant estuarine system defaunation and seagrass kills. Following the 1988 plug removal and associated environmental impacts, a series of public meetings were held in Homestead and West Palm Beach to solicit comments from the public and staffs of local, state and federal agencies concerned with the issue. District staff has since developed six recommended changes in the system intended to improve environmental and water management throughout the C-111 Basin (MacVicar, 1988).

District Interim Proposals for the C-111 system. According to MacVicar (1988), two water management issues drive the hydrologic behavior of the C-111 System. First, design changes in the upper basin have resulted in a major increase in the annual volume of water that flows to the lower end of the system. Second, the design of S-197 provides limited management flexibility, therefore unacceptable environmental effects occur as the result of each major storm event. To remedy these problems, the District has proposed six immediate changes for the C-111 Basin, three within the upper basin and three within the lower basin (**Figure 61**). These six changes are summarized below and are recommended as temporary improvements that can be implemented until the long-term federal plan for the basin is constructed:

Upper Basin Recommendations

A.1. Install a culverted water control structure in the L-31N canal north of the residential area and just south of the intersection with C-1W. **Figure 62.** was taken from the District's report on the wet season test of flow to NESRS. It indicates that more than 80 percent of the flow through S-331 originates as seepage entering L-31N north of C-1W. The proposed culverts would allow an upstream water level of 6.0 feet compared to the 4.5 feet that is now held in the wet season. This would greatly reduce the seepage entering the canal and the additional head would allow the seepage that is collected to be diverted through C-1W rather than C-111.

This structure would be an intermediate solution that could be removed when the East Everglades plan is implemented. It would be sized to have minimal impact on the water delivery function of the conveyance system and in an extreme drought could be removed to allow increased water delivery to south Dade. No adverse effects on adjacent property are expected since there is very little development near L-31N north of C-1W and the water level in the canal was routinely above 6.0 ft prior to 1983.

A.2. Revise the operational guidelines for S-176. To compensate for the increased flow to the south, as a result of pumping S-331 for flood control, the operating criteria at S-176 were lowered to provide additional flood protection for the area between S-331 and S-176 during the wet season. Once the majority of the seepage flow is eliminated the operating range can be raised. The District proposes an increase in the wet season level from 4.3 ft to 4.8 ft at S-176. This is well within the design range of the system and should not pose any additional risk to the adjacent property, once the L-31N culverts are in place.

Another benefit of raising the water level at S-176 is an enhanced ability to divert water from L-31N to Taylor Slough. With an operating level of 4.5 ft in L-31W water cannot be diverted from L-31N to northern Taylor Slough. A 4.8 ft stage at S-176 will allow more diversion to L-31W and further reduce the load on the south end of C-111.

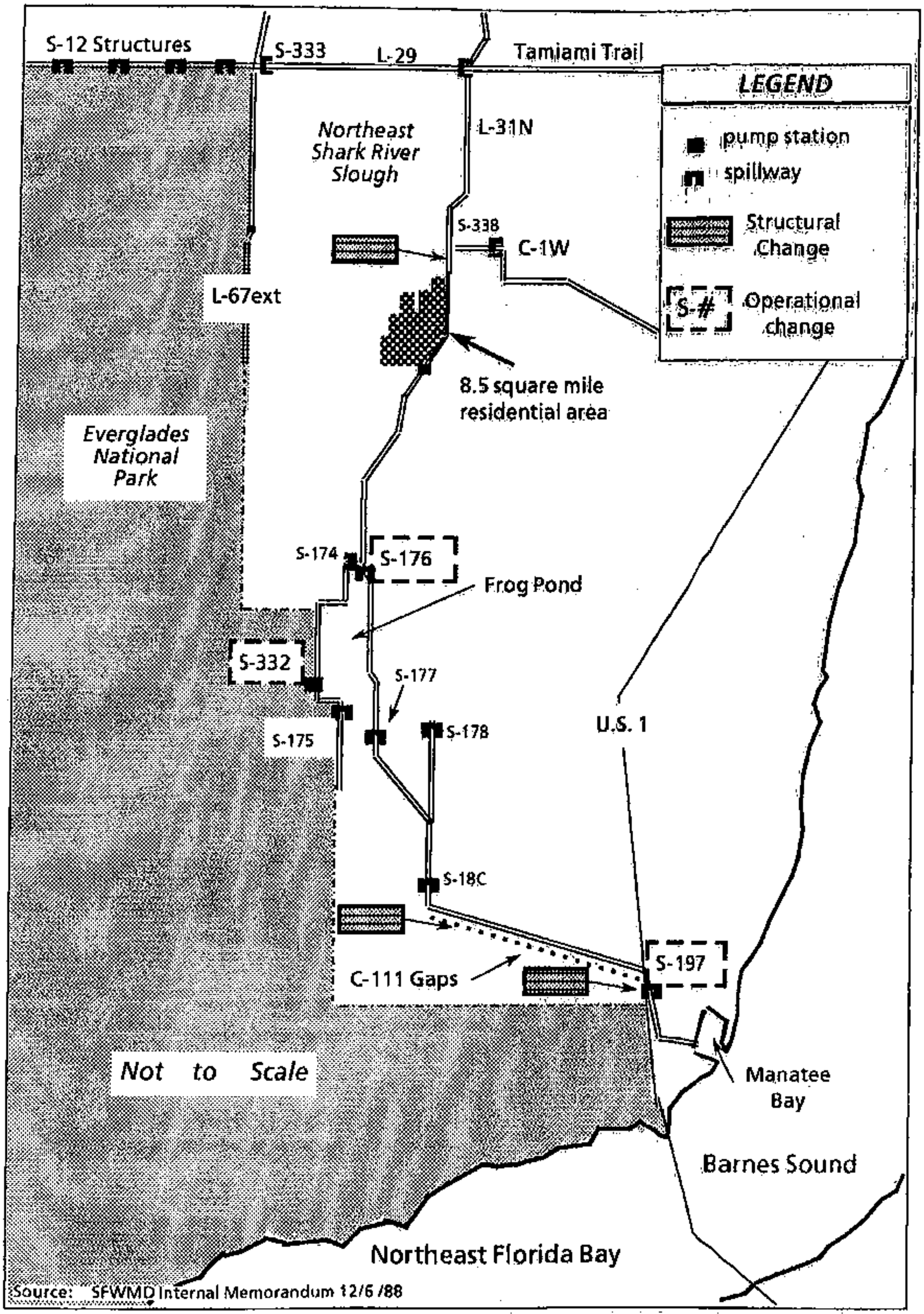
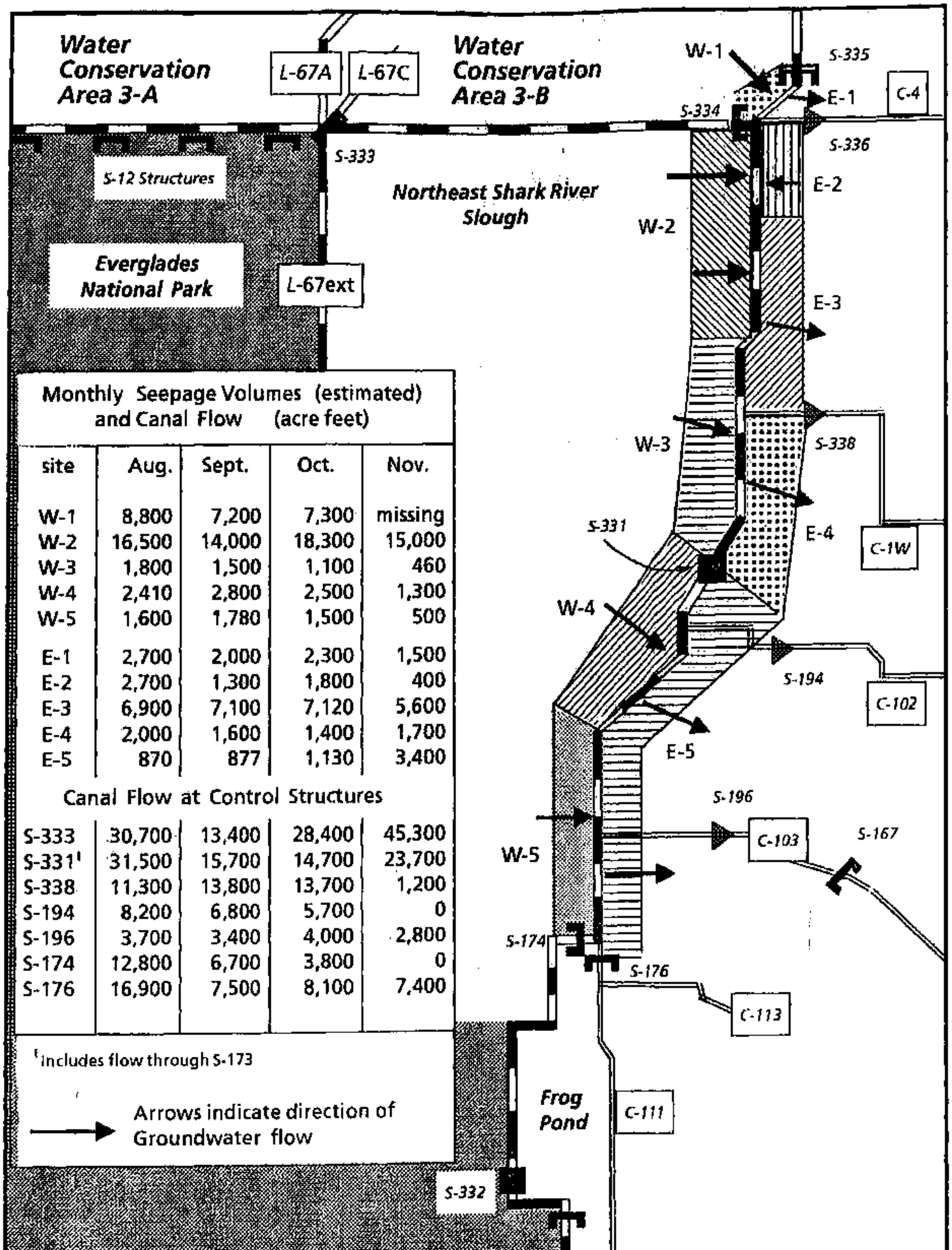


Figure 61. Generalized Diagram of C-111 Basin with Location of Proposed Changes.



Monthly Seepage Volumes (estimated) and Canal Flow (acre feet)

site	Aug.	Sept.	Oct.	Nov.
W-1	8,800	7,200	7,300	missing
W-2	16,500	14,000	18,300	15,000
W-3	1,800	1,500	1,100	460
W-4	2,410	2,800	2,500	1,300
W-5	1,600	1,780	1,500	500
E-1	2,700	2,000	2,300	1,500
E-2	2,700	1,300	1,800	400
E-3	6,900	7,100	7,120	5,600
E-4	2,000	1,600	1,400	1,700
E-5	870	877	1,130	3,400
Canal Flow at Control Structures				
S-333	30,700	13,400	28,400	45,300
S-331[1]	31,500	15,700	14,700	23,700
S-338	11,300	13,800	13,700	1,200
S-194	8,200	6,800	5,700	0
S-196	3,700	3,400	4,000	2,800
S-174	12,800	6,700	3,800	0
S-176	16,900	7,500	8,100	7,400

[1] Includes flow through S-173

Figure 62. Idealized Flow Sections used to Compute Estimates of Groundwater Flow in the Vicinity of L-31N During the 90-Day Test in 1984 (MacVicar, 1985).

A.3. More effective use of S-332. Pump station S-332 moves water from L-31W to Taylor Slough. It is now operated to supply a minimum monthly allotment of water to the slough with no variation in response to rainfall or drought conditions. The agreement between the Corps, SFWMD, and NPS states what the minimum monthly flow rates are, and that during flood periods such rates may be exceeded, up to capacity of the pump station, upon mutual agreement of the parties. Although its capacity is limited, the station could clearly be put to more effective use during wet periods when flow is now being shunted to the south end of the slough through S-175. The District will work with the the USCOE and ENP staff to accomplish more meaningful operation of these pumps.

Lower Basin Recommendations. The problems of the lower C-111 basin are dominated by the lack of flexibility in the original design and the extent of the environmental damage whenever the S-197 "plug" must be removed. Although influenced by the increase in annual volumes passing through S-18C, it is predominately a storm response shortcoming built into the system that leads to the need to pull the plug. We are recommending two structural and one operational change for this reach of the canal.

B.1. Install additional culverts in the plug. In the hydraulic analysis prepared for the C-111 GDM, the USCOE estimated that flow through S-197 during a design storm could be reduced by 67 percent simply by installing an operable structure rather than an earthen plug. A control structure allows the flow to be reduced as soon as conditions in the developed area improve. With the plug the District must wait until almost all flow has subsided before the plug can be replaced.

B.2. Change the operational policy for the S-197 culverts. A system must be devised that allows gradual opening of the culverts (existing and new) as water levels rise upstream of S-18C. Implementation of an appropriate schedule and control elevations to provide for gradual, pre-flood releases would cause much less harm to Barnes Sound and may eliminate the need for full scale discharge for some flood events. Any proposed change to the operating rules must be reviewed by all interested parties before implementation.

B.3. Remove the westernmost spoil on the south side of C-111 between S-18C and C-110. Flow from C-111 to the panhandle of ENP is accomplished by a series of gaps in the spoil bank on the south side of the C-111 canal upstream of U.S. Highway 1. Most of the flow passes through the eastern-most gaps since the land elevation is lower and the distance to Florida Bay is shorter. Enlarging the gaps at the western end would have little affect on the routine flows to the panhandle. However, during storm events when water levels are up in the canal, more water may be diverted overbank in the western reach with the removal of the spoil material. This is an expressed interest of Everglades National Park and would not be pursued without the full support of Park staff.

Recommendations from Everglades National Park. (Ogden and Johnson, 1988).

1. *Unnatural Water Impoundment.* Remove the C-109 and C-110 levees to prevent unnatural impoundment of surface water north of the lower C-111.

2. *Modification of Culverts.* Remove or lower the flashboards in culverts along the northern side of the lower C-111 to allow more natural flows south and southeast in this region and reduce some impoundment of water north and west of the junction of the C-111 and U.S. Highway 1.
3. *Culverts under US 1.* As proposed by the Florida Department of Transportation, install additional culverts and bridges along U.S. Highway 1 to allow more natural flows through this area. The culverts and bridges should be located at historical flow-ways to restore pre-U.S. Highway 1 connections.
4. *Acquire Additional Southern Marshes.* Acquire for public ownership the belt of marshes and estuaries between U.S. 1 and Mangrove Point. These areas are significant nesting habitat for wading birds and crocodiles.

3. Water Quality.

Surface Water Quality. Descriptions of water quality sampling station locations have been compiled from the literature for ENP (**Table 47 and Figure 44**) and for the East Everglades and C-111 Basins (**Table 64 and Figure 63**). Much of the data in this report is more than ten years old. There are several sources of more recent raw data including SFWMD, ENP, and DERM. Some of these more recent studies are briefly described, but no attempt has been made to analyze or interpret these data. Selected data summaries are included in Appendix C.

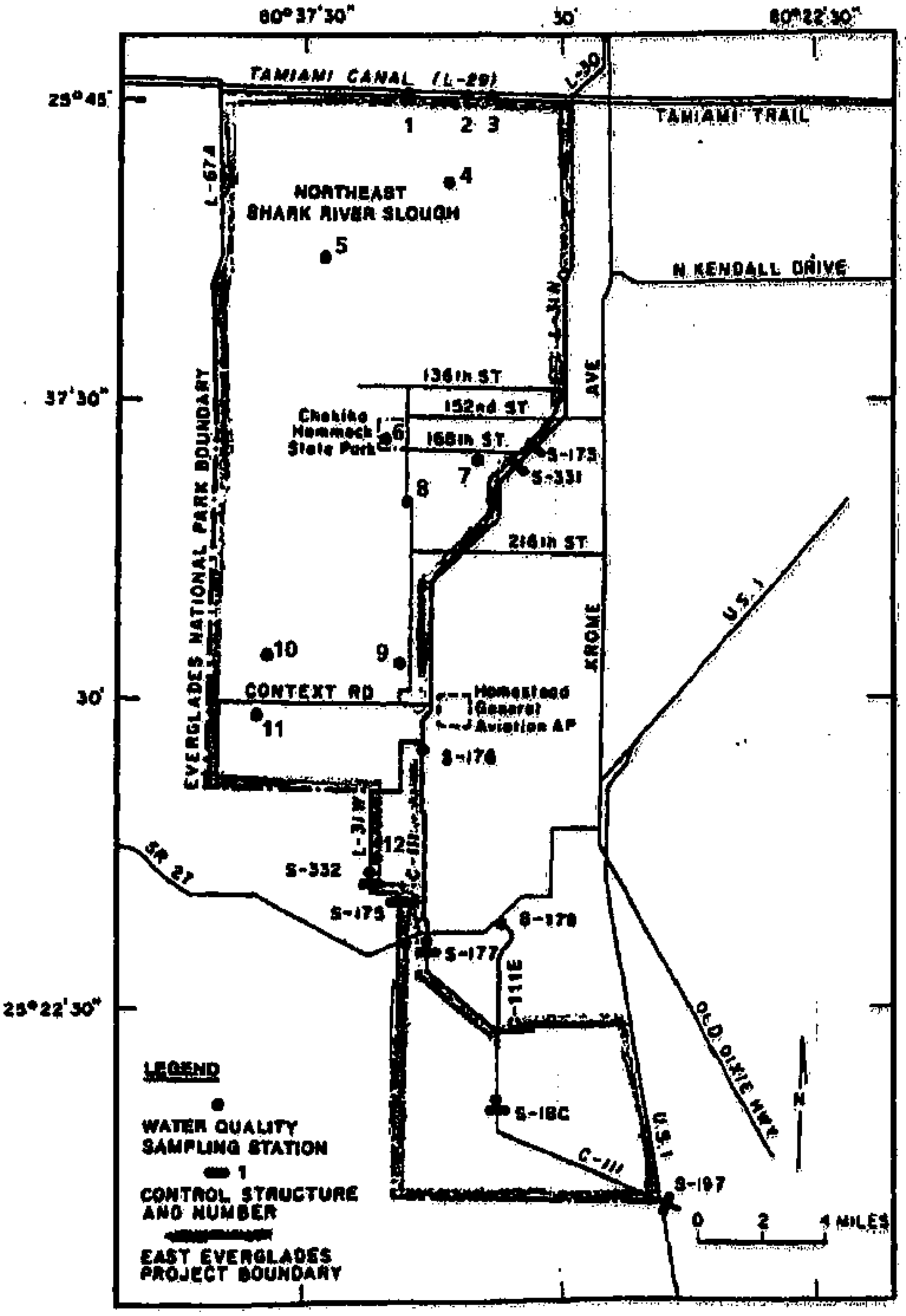
Table 64. Surface Water Quality Stations in the East Everglades

Station Number*	Description	Reference
Stations within the East Everglades		
1	Bridge 45 on Tamiami Canal	McPherson, 1973
2	Bridge 53 on Tamiami Canal	Waller, 1981
3	Coopertown	Waller, 1982b
4	NESRS Freshwater Station	Waller, 1982b
5	NESRS Freshwater Station	Waller, 1982b
6	Chekika Hammock State Park	Waller, 1982b
7	Rocky Glades Residential Area	Waller, 1982b
8	Grossman Road Borrow Canal	Waller, 1981
9	Rock-Plowed Tomato Field	Waller, 1982b
10	Context Road (undeveloped area)	Waller, 1982b
11	Context Road (undeveloped area)	Waller, 1982b
12	Cracker Jack Slough Agricultural Area	Waller, 1982b
S-332	Pump Station at L-31W and Taylor Slough	Germain and Shaw, 1988
Stations along C-111		
S-176	Structure at Head of C-113 on C-111	Germain and Shaw, 1988
S-177	Floodgate at C-111 and US27	Germain and Shaw, 1988
S-178	Floodgate at C-111E and US27	Germain and Shaw, 1988
S-18C	Structure on C-111, South of US27	Germain and Shaw, 1988

*Source: Based on Data Compiled by CH_2MHill

East Everglades. This discussion of East Everglades water quality includes Northeast Shark River Slough (NESRS) and Taylor Slough. Data for the Frog Pond are included in the Taylor Slough section. The USGS and Dade County cooperated in a study to analyze effects of land use on surface water quality between June 1978 and October 1978. This study was initiated because of concern regarding potential effects of East Everglades residential, agricultural, and recreational development on the quality of water delivered to the ENP. The results of this and other studies are included in the discussions of Northeast Shark River Slough and Taylor Slough.

Figure 63. Location of Surface Water Quality Sampling Stations in the East Everglades.



Source: Modified from Schneider and Waller, 1980

Northeast Shark River Slough. Surface water flow to NESRS was almost eliminated with the completion of L-29 in 1963. Seepage occurred from WCA-3B under L-29 to the borrow canal, from which waters subsequently flowed to the slough through the culverts under Tamiami Trail. However, this is only a small percentage of the historical flow in the area (Neidrauer and Cooper, 1989). The District's Rainfall Plan has attempted to redistribute flow across the entire slough according to actual rainfall frequency and accumulated volumes (i.e., restoring overland flow to NESRS via S-333 and the L-29 Canal). Because of the increases in water delivery to NESRS and water supply deliveries to south Dade County, concerns about the quality of water in the L-29 canal have increased.

Surface water quality data for areas within Northeast Shark River Slough are limited. Surface water quality during the wet season and its relationship to land use in Northeast Shark River Slough were studied for several land use types (Waller, 1982b). Areas sampled included Coopertown (station 3), the oldest settlement in Shark River Slough, Chekika Hammock State Park (station 6), and Rocky Glades residential area (station 7) as shown in **Figure 63**), also referred to as the 8.5-square-mile residential area. Water quality at Coopertown seemed to be influenced by the quality of the water coming from Tamiami Canal for the period of record June 1978 to October 1978 (Waller 1982b). During rainfall events, water quality did not significantly change. However, the insecticide, malathion, was detected in Chekika Hammock State Park (**Appendix C, Table C-21**) (Waller, 1982b).

Relatively little current information exists concerning the quality of water that flows through culverts under Tamiami Trail from the L-29 Borrow to Northeast Shark River Slough. Data for the period 1972-1980 (Flora and Rosendahl, 1982) indicate that most nutrient concentrations discharged into Northeast Shark River Slough were among the lowest in south Florida at that time. Similar results were reported by Waller (1982a) where average total phosphorus concentrations at the Coopertown site was 0.01 mg/L while the Bridge 53 site averaged 0.022 mg/L (Waller, 1981) (**Figure 63**) (**Appendix C, Table C-16**). More recent data (1979-1988) collected by SFWMD at S-333 indicate that annual flow-weighted total phosphorus concentrations averaged 0.026 over the ten year period of record (**Table 65**). Highest yearly average total phosphorus concentrations at S-333 occurred in 1985 (0.043 mg /L) representing a phosphorus loading of 17 metric tons per year to L-29.

Table 65. Surface water inflows, flow-weighted total phosphorus concentrations and phosphorus loading at S-333, 1979-1988.

Year	Inflow (acre ft.)	Flow-Weighted Total P (mg/L)	Total P Loading (metric tons)
1979	37,698	.018	0.8
1980	35,991	.015	0.7
1981	29,681	.022	0.8
1982	80,211	.015	1.4
1983	112,197	.008	1.5
1984	101,583	.026	3.2
1985	327,458	.043	17.2
1986	278,511	.027	9.3
1987	175,702	.017	3.7
1988	208,301	.004	1.2

Source: SFWMD, Unpublished data

Coliform bacteria, typically used as an indicator of domestic sewage and agricultural runoff, was monitored at three sites in Northeast Shark River Slough . Sites in Coopertown and Rocky Glades (both residential) and Chekika Hammock State Park (recreational) were sampled for total, fecal, and fecal streptococci coliforms (**Appendix C, Table C-22**). Total coliform counts at Chekika Hammock State Park exceeded the 20,000 cells per 100mL standard for drinking water. The fecal coliform standard of 2000 cells per 100mL was equaled or exceeded at the Coopertown and Rocky Glades sites during one sampling period (Waller, 1982b). Ratios of fecal coliforms to fecal streptococci exceeding 4.0, suggesting contributions from human sources. Ratios on one occasion (July 28, 1978) were 8.70 at Coopertown, and 8.89 at Rocky Glades Canal (Waller, 1982b). Water quality was also analyzed during intense rainfall events to determine the effect of increased runoff. Water quality did not consistently change during intense rainfall events except that malathion, used for insect control, (**Appendix C**) was detected in the State Park (Waller, 1982b).

Taylor Slough. Little published data exists for waters delivered to Taylor Slough. Nutrient concentration data for waters delivered to Taylor Slough via S-332 have been collected periodically by SFWMD since 1983. These data is in unpublished, but 1984 to 1987 annual averages can be found in **Appendix C, Tables C-24 through C-27)**. During the 1978 wet season, (June to October) Waller (1982b) studied the effects of land use on surface water quality. Cracker Jack Slough agricultural area and a rock-plowed tomato field were chosen to represent two common land uses in Taylor Slough. Water quality parameters from these areas were compared to baseline sites in Northeast Shark River Slough. Water quality at the rock-plowed tomato site had higher concentrations of organic nitrogen, orthophosphate and higher turbidity than the baseline sites (Appendix C). These elevated concentrations were indicative of agricultural practices (Waller, 1982b). In addition, elevated concentrations of micronutrients commonly used in agricultural practices were found. Water quality of the Cracker Jack Slough site was comparable to baseline values.

Grossman Road Borrow Canal, located southeast of Chekika Hammock State Park, was also sampled during another USGS study (Waller, 1981). Land use information was not provided in the report, but according to land use maps, the canal drains open land, some agricultural land and part of the Rocky Glades residential area. Comparison of the borrow canal to the baseline site (Context Road) showed that the two areas did not differ greatly in nutrient concentration. The borrow canal did have higher conductivities, sodium, chloride, and sulfate concentrations, a characteristic of agricultural activity (Waller, 1981).

Pesticide detections in the water column have been rare in Taylor Slough (Appendix C). Atrazine (Pfeuffer, in press) and toxaphene (Pfeuffer, 1985) were each detected on one occasion at S-332 . Sediment samples in the East Everglades were taken one time, in 1979 (Waller, 1983), however sample sizes were limited. Chlorinated hydrocarbons were detected in all land use areas, except Chekika Hammock State Park. Pesticides were primarily of the DDT family, chlordane, and dieldrin. The range of pesticides tested for was also limited. No recent published information is available for the East Everglades.

<u>C-111 Basin</u>. Little water quality data exists for the C-111 basin prior to the construction of the C-111 canal in 1962 (SFWMD, 1990). Earliest water quality data were collected by Wilson (1974) in a study of algal communities during the period 1969 to 1971. In this study, total phosphorus was reported to range from 0.005

to 0.100 mg/L, nitrates from 0.01 to 0.05 mg/L, and pH from 7.8 to 8.6. The sampling site was located about 300 feet south of the C-111 canal (Wilson, 1974).

Water quality at S-18C has been collected by the SFWMD since 1983. A District report (SFWMD, 1990) provides additional water quality information for the C-111 basin for the period October 1, 1985 to September 30, 1987. In this study, water quality of the C-111 canal was characterized as "good" to "excellent". The report also concluded that the average total phosphorus concentrations at S-18C from 1983-1987 ranged from <0.004 to 0.026 mg/L with an average concentration of 0.007 mg/L. These values were comparable to total phosphorus values observed at interior C-111 marsh sites sampled over the same period of record (SFWMD,1990). Compared to other south Florida canals which drain southern Florida agricultural lands, such as the Miami or Hillsboro canals, C-111 canal water contains moderate concentrations of dissolved minerals (**Table 66**) and low concentrations of nutrients (SFWMD, 1990). Yearly averages for water quality parameters at S-18C for 1983-1987 can be found in **Appendix C, Tables C-22 through C-27.**

Table 66. Comparison of nutrients, chloride and specific conductance within south Florida canals which drain agricultural lands.

Parameter	C-111 at S-18C	L-67A at S-333	L-67A at S-151	Miami Canal at S-8
Total Phosphorus (mg/L)	.007	.016	.023	.102
Total Nitrogen (mg/L)	1.14	2.22	2.33	3.37
Specific. Cond.(umhos/cm)	585	743	873	786
Chloride (mg/L)	66	87	110	88

Source: SFWMD 1990

A draft report of pesticide concentrations is available for 1987-1988 (Pfeuffer, in press). Atrazine was detected, with concentrations found at the S-176, S-177, S-178, and S-18C structures in April 1988. Pesticide data have been summarized for the C-111 Basin in **Appendix C, Tables C-20 and C-21**. Sediment samples taken in 1972-1974 (Waller and Earle, 1975) at S-175 showed trace (.2 ppb) amounts of DDE. Samples taken in 1982-1983 at nearby S-332 (Pfeuffer, 1985) showed the widespread presence of chlorinated hydrocarbons; however; the 1984-1988 sediment samples did not show pesticides at this site (Pfeuffer, in press). Analysis of sediment samples taken in canals leading into the C-111 Basin (S-176, S-177, S-178, S-18C) have indicated the presence of pesticides. Chlordane has been detected periodically in samples taken at S-177. A summary of pesticide detections and dates for this area is found in **Table 67.**

Dade County DERM Canal Monitoring Program. Under a general canal monitoring program, selected canals in Dade County are sampled quarterly by Dade County Department of Environmental Resources Management (DERM). Samples are analyzed for a variety of parameters, including nutrients, alkalinity, biological oxygen demand (BOD), chlorine, pesticides, and herbicides. L-31N is the only canal within the ENP SWIM Planning Area currently monitored under the general Canal Program; three sites along this canal are monitored. Historically, some sampling was performed in C-111. Samples were collected monthly in 1984 and every 2 months in 1985. However, only a limited set of chemical parameters (nitrate plus nitrite, conductivity, and dissolved oxygen) were monitored. Coliforms were also analyzed in 1985.

Table 67. Summary of Positive Background Pesticide Monitoring Data Sampling Event and Date.

Station	Win 1984 11 5 1984	Sum 1985 7 17-19 1985	Win 1985 2 11-12 1986	Sum 1986 6 25-26 1986	2nd Qrt 1 6-28 1987	3rd Qrt 4 13-15 1987	4th Qrt 7 20-22 1987	1st Qrt 10 26-28 1987	2nd Qrt 2 22-24 1988	3rd Qrt 4 11-13 1988	4th Qrt 7 25-27 1988
S-332	-/< H	-/< H	-/< H	-/< H	-/< WH	</- W	</< WH	</< WH	</< WH	1.0/< atrazine WH	</< WH
S-18C	-/< H	-/< H	-/< H	-/< H	-/< WH	</- W	</< WH	</< WH	</< WH	0.8/< atrazine WH	</< WH
S-176	-/< H	-/< H	-/< H	-/< H	-/< WH	</- W	</< WH	</< WH	</< WH	0.5/< atrazine WH	</< WH
S-177	/7.3 DDE H	-/< H	-/< H	-/< H	0.41/< 2, 4, 5-TP WH	</- W	</< WH	</< WH	</1.8 DDD 5.0 DDE WH	0.7/29 atrazine DDE WH	</15 DDE WH
S-178	-/10 DDE H	-/< H	-/< H	-/< H	</< WH	</- W	</< WH	</< WH	</< WH	13.2/< atrazine WH	</< WH
S-12C	-/< H	-/< H	-/1100 diazinon H	-/< H	</< WH	</- W	</< WH	</< WH	</1.2 heptachlor epoxide WH	</< WH	</< WH
US41-25	-/4.9 DDE H	-/< H	-/600 aldrin 4200 malathion H	-/< H	</< WH	</- W	</369 2, 4-D WH	</< WH	</3.4 DDE WH	</< WH	</< WH
S-9	-	-/< H	-/< H	-/< H	</< WH	</- W	</< WH	</1200 paraquat WH	</< WH	</< WH	</< WH

(a) compounds above detection limit in surface water in ug/L
b) compounds above detection limit in sediment in ug/Kg
(c) < all compounds below detection limit
d) - = not sampled
W = surface water sampled,
H = sediment sampled,
- = not sampled
Source: Data compiled for SWIM report

DERM Intensive Canal Survey. Each year, DERM designates one canal from its Canal Program to be studied more intensely. L-31N was designated in 1987. Six sites were sampled on a quarterly basis for both water and sediment samples. Analyses included physical properties, nutrients, major inorganic chemicals, trace metals, biological and chemical oxygen demand (BOD and COD), and a variety of pesticides. Results from the L-31N Canal survey are in unpublished form.

Pesticides in Canal Sediments and Soils. Samples taken in 1972-1974 (Waller and Earle, 1975) at S-332, an ENP delivery station, showed trace amounts of DDD and DDE; samples taken in 1982-1983 (Pfeuffer, 1985) showed the widespread presence of chlorinated hydrocarbons; but in 1984-1988 soil samples did not show pesticides at this site (Pfeuffer, in press). Soils samples taken in canals leading into the C-111 Basin (S-176, S-177, S-178, S-18C) have shown detections of contaminants. Chlordane has been detected periodically in samples taken at S-177.

Few published reports of soils analyses within the ENP exist. McPherson (1971) noted the presence of DDT and its breakdown products at Cottonmouth Camp. Waller (1982) reported trace amounts of chlorinated hydrocarbons (primarily the DDT family, chlordane, and dieldrin) in nearly every station of the ENP. The number, location, and sampling frequency of the stations used in Waller's (1982) pesticide analysis were unspecified.

Waller (1983) presents information on soils sampled in the East Everglades. Samples were taken one time, in 1979, however sample sizes were limited. Chlorinated hydrocarbons were detected in all land-use areas, except Chekika Hammock State Park. Pesticides were primarily of the DDT family, chlordane, and dieldrin. The range of pesticides tested for was also limited. No recent published information is available for the East Everglades.

Water Quality Impacts on Receiving Waters. The most recent removal of the S-197 structure from the mouth of the C-111 released large quantities of freshwater and suspended sediments into Manatee Bay, Barnes Sound and adjacent estuarine areas. Portions of this water, due to hydrologic connections, moved into northeast Florida Bay. This area is connected to John Pennekamp State Park by an artificial channel through North Key Largo at the Adams Waterway. Water sampled in this canal, after the removal of the S-197 structure, indicated the presence of abnormally high concentrations of pesticides (Skinner, 1988). The water samples taken at this time had unusually high suspended solids and it is believed that the compounds detected were bound or adhered to suspended particles. This is indicated by the type of compound found in the analysis and its normal residence time in water. These compounds are typically bound in the sediments and because of their chemistry are not dissolved in the water column. A summary of positive pesticide samples for this area and time is found in **Table 67**. A listing of known pesticides in District canals and results of previous sediment monitoring are provided in **Table 67.**

Freshwater releases from C-111 canal periodically have major impacts on water quality conditions in Barnes Sound. In addition, local interests, agency personnel and conservation groups have expressed increasing concerns that residential development along north Key Largo and intensified farming and urban development south and east of Homestead may contribute to deteriorating water quality conditions in Florida Bay and adjacent marine areas. Other potential sources of contamination for Barnes Sound and Manatee Bay are nutrients from live-aboard boats and septic tank seepage, hydrocarbon contamination from runoff and boating activity, and trace metal and pesticide contamination from runoff and periodic canal discharges. Few data, however, exist to document these suspected problems.

Ideally, all sites where water quality affects the ENP planning area should be examined and monitored. This includes S-332 for Taylor Slough; L-176, L-177, L-178, and S-18C for the C-111 Basin; and the S-12 structures for the northern boundary of the study area. Current published water quality data for the Taylor Slough Basin are sparse after 1974 and data for the C-111 Basin are almost non-existent. Data from expanded monitoring programs, such as the estuarine monitoring and assessment projects that are proposed in this plan, may be required before clear demonstration of water quality impacts will be possible in these areas.

Groundwater Quality. Data from numerous groundwater quality sampling studies have been compiled from the literature for the East Everglades and C-111 Basins. Results of these studies are summarized in **Table 68** to indicate those parameters that exceeded background levels.

Groundwater Contamination. Results of SFWMD review of Metro-Dade and FDER files from 1976, 1978, and 1983 revealed that in 1976, while installing a sewer main in south Dade County at the Everglades Labor Camp, an old pesticide disposal site was uncovered. Samples showed 3.25% (32,500 ppm) parathion in broken containers in the groundwater at the original time of discovery. In 1983, an investigation was begun by FDER to determine the extent of groundwater

Table 68. Summary of Groundwater Quality Parameters Exceeding Background in the East Everglades.

Land Use Area	Parameters		Source
Howard Drive Agric. Area	Specific Conductance Total Organic Nitrogen	Iron Ammonium Total Nitrogen	Waller, 1983
Citrus Grove	Specific Conductance Organic Nitrogen Nitrate	Potassium Iron Total Nitrogen	Waller, 1983
Rock-plowed Tomato Field	Potassium		Waller, 1983
Cracker Jack Slough Agric. Area	Potassium		Waller, 1983
Coopertown	Color Specific Conductance Ammonia Total Organic Nitrogen	Alkalinity Iron Organic Nitrogen Total Nitrogen Orthophosphate	Waller, 1983
Richmond Dr. Resid. Area	Specific Conductance Total Nitrogen	Total Organic Nitrogen	Waller, 1983
Chekika Hammock State Park	Specific Conductance Organic Nitrogen Total Nitrogen Orthophosphate	Potassium Iron Ammonia Total Organic Carbon	Waller, 1983
Northeastern Shark River Slough	Alkalinity Calcium Magnesium Chloride Copper Lead Orthophosphate Organic Nitrogen Total Organic Carbon	Specific Conductance Sodium Fluoride Iron Manganese Ammonia Total Nitrogen Total Inorganic Carbon	Waller, 1981
Context Road at Bridge 27	Calcium Manganese	Iron	Waller, 1981

Note: The above-listed parameters are those which usually exceed background (uncontaminated groundwater) conditions by one standard deviation or more.

contamination of at this site. Toxaphene was discovered in ground water to the northeast of the original site at levels of 9.3 and 8.4 micrograms per liter (ppb). Parathion was tested for and not detected. No source of toxaphene was determined. At this writing, the status for cleanup of this site is unknown.

Spraying of pesticides by airplane is a common method of controlling insect pests in south Florida. These field spraying operations are often a source of long-term contamination after the original operation has ended because historically, the standard practice for cleaning the spray tanks was to dump the tank at the end of the field. Field spraying operations are responsible for a number of Superfund sites in South Florida (USEPA, 1986. National Priorities List Fact Book. Washington, D.C. 94 pp). Groundwater should be sampled more extensively in areas of south Dade County that are known to have been used for spray operations. Pesticide and herbicide use has been identified as a threat to drinking water, and natural flora and fauna in this region (Scheidt, 1988; Walters, 1987; Mattraw *et al.* 1987).

DERM Ground Water Ambient Network. In 1981, DERM initiated a groundwater monitoring network to provide a long-term, groundwater quality database in Dade County. This network included sites in the vicinity of the proposed west wellfield near the East Everglades. The purpose of the program was to determine local trends and pollution control programs. The program was suspended in 1985.

DERM/FDER State Ground Water Ambient Network. The State Ground Water Ambient Network replaced DERM's groundwater network in 1986. This program monitors wells from DERM's Ground Water Ambient Network, plus additional wells. Initial samples were analyzed once for an extensive list of parameters. The 1986-1987 network included approximately 85 wells with depths ranging from 10 to 100 feet. The 1988 network reduced the number of wells to 60. Analyses include physical parameters, nutrients, inorganic ions, organic chemicals, trace metals, radionuclides, cyanide, and indicator bacteria.

Short-Term Studies. On behalf of the Dade County Planning Department, the USGS sampled groundwater in the eastern Everglades in 1978 and 1979 (Waller, 1981). Parameters analyzed included nutrients, major ions, and metals. This effort was to establish baseline water quality conditions and to provide information for future development plans in the East Everglades. This work showed elevated levels of nutrients and some metals (Waller, 1981).

In 1984, prompted by FDER and the Water Quality Assurance Act of 1983, the District initiated the South Dade Agricultural Pilot Study to investigate effects of certain agricultural land uses on groundwater quality within the Biscayne aquifer (Anderson, 1986). Samples were collected from 20 West Dade/East Everglades monitoring wells twice in 1984 and analyzed for pesticides, metals, and nutrients. Results of this study identified the presence of 4,4'-DDT, Aldrin, and Dieldrin in excess of potable water standards in the monitoring wells (Anderson, 1986). Existing SFWMD data indicate that pesticide residues occur occasionally in South Dade County monitoring wells. The exact magnitude and sources of this contamination, and the potential impacts on potable water supplies, are presently unknown.

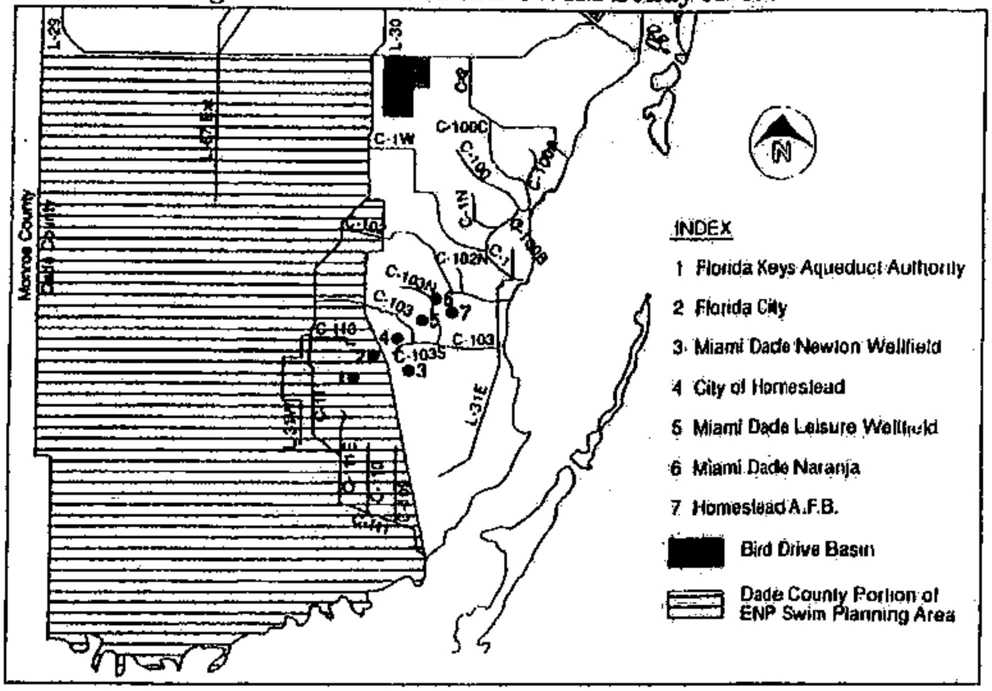
Wellfields. Several major public water supply wellfields lie within or adjacent to the study area including the Homestead Air Force Base well field in the EEA, several within the C-111 Basin (Florida Keys Aqueduct Authority, City of Florida City) and several just east of the C-111 Basin (City of Homestead, Miami Dade Water and Sewer Authority (MDWSA) Leisure, MDWSA Naranja, and MDWSA Newton. In addition, a major new wellfield, the MDWSA West Wellfield which is proposed to serve South Dade County, will likely be sited to the east of L-31, in the Bird Drive area (**Figure 64**) (Discussion 1989 with Jean Evoy, Metro-Dade County, Planning Department).

Groundwater Quality Data. Groundwater quality data from published literature were compiled to provide an overview of available reviewed information. Descriptions of groundwater quality station locations have been compiled from the literature for the USGS Land Use/Water Quality studies (**Table 69, Figure 65**), for the District South Dade Agricultural Pilot Study (**Table 70, Figure 66**), and for the DERM Chlorinated Pesticide Survey (**Table 71, Figure 67**). Groundwater quality summary data from published sources are compiled in **Appendix C** as follows:

Table C-28	Nitrogen, phosphorus, TIC, and TOC
Table C-29	Alkalinity, specific conductance, and major ions
Table C-30	Metals
Table C-31	Pesticides in groundwater: Chlorinated hydrocarbons
Table C-32	Pesticides in groundwater: Organophosphates and other compounds
Table C-33	Pesticides in soils: Chlorinated hydrocarbons
Table C-34	Pesticides in soils: Organophosphates and other compounds
Table C-35	Coliforms

Groundwater Quality Relationship to Land Use. Groundwater quality sampling within the ENP SWIM Planning Area has occurred primarily in the East Everglades, prompted by concerns over effects of land uses (agricultural, residential,

Figure 64. Major Public Water Supply Wellfields within and adjacent to the Everglades National Park SWIM Study Area.



Source: Based on Data Compiled by CH_2MHill

recreational) on the Biscayne aquifer and the source of most of Dade County's drinking water. Results of Groundwater quality studies for pesticides are summarized in **Table 72.**

Pesticides in Soils. Data for insecticides, herbicides, and PCBs in soils have been compiled because of potential impacts on water quality (**Appendix C, Tables C-33 and C-34**). Some studies that have analyzed soils from the same sites at different times. For example, S-12C was sampled in 1972-1974 (Waller and Earle, 1975), in 1982-1983 (Pfeuffer, in press), and in 1984-1988 (Pfeuffer, 1989). Chlordane and the DDT family (DDE, DDD, DDT) were detected during the early study period but not in any of the subsequent studies. This should emphasize the need for a long-term, continuous sampling program at the same sites.

Potential Water Quality Impacts on Groundwater. The Biscayne Aquifer is the prime source of drinking water for all municipal water systems south of Palm Beach County, and is the primary source of water for agricultural and municipal use in Dade County. The Biscayne Aquifer is highly permeable and vulnerable to contamination through its recharge zone, and it is the sole source of drinking water for a large part of southeast Florida. Therefore, the U.S. Environmental Protection Agency (EPA) has designated the Biscayne Aquifer as a "sole source aquifer."

Dispersion and adsorption tend to reduce the concentrations of polluting substances, and seasonally heavy rainfall and canal discharge contribute toward diluting and flushing the upper aquifer zones. Expansion of urban and/or agricultural development into recharge areas, and the attendant runoff could contribute contaminants, and affect water quality in down-gradient sections of the aquifer (Klein and Hull, 1978).

Figure 65. Groundwater Monitoring Locations for USGS Land Use/Water Quality Studies

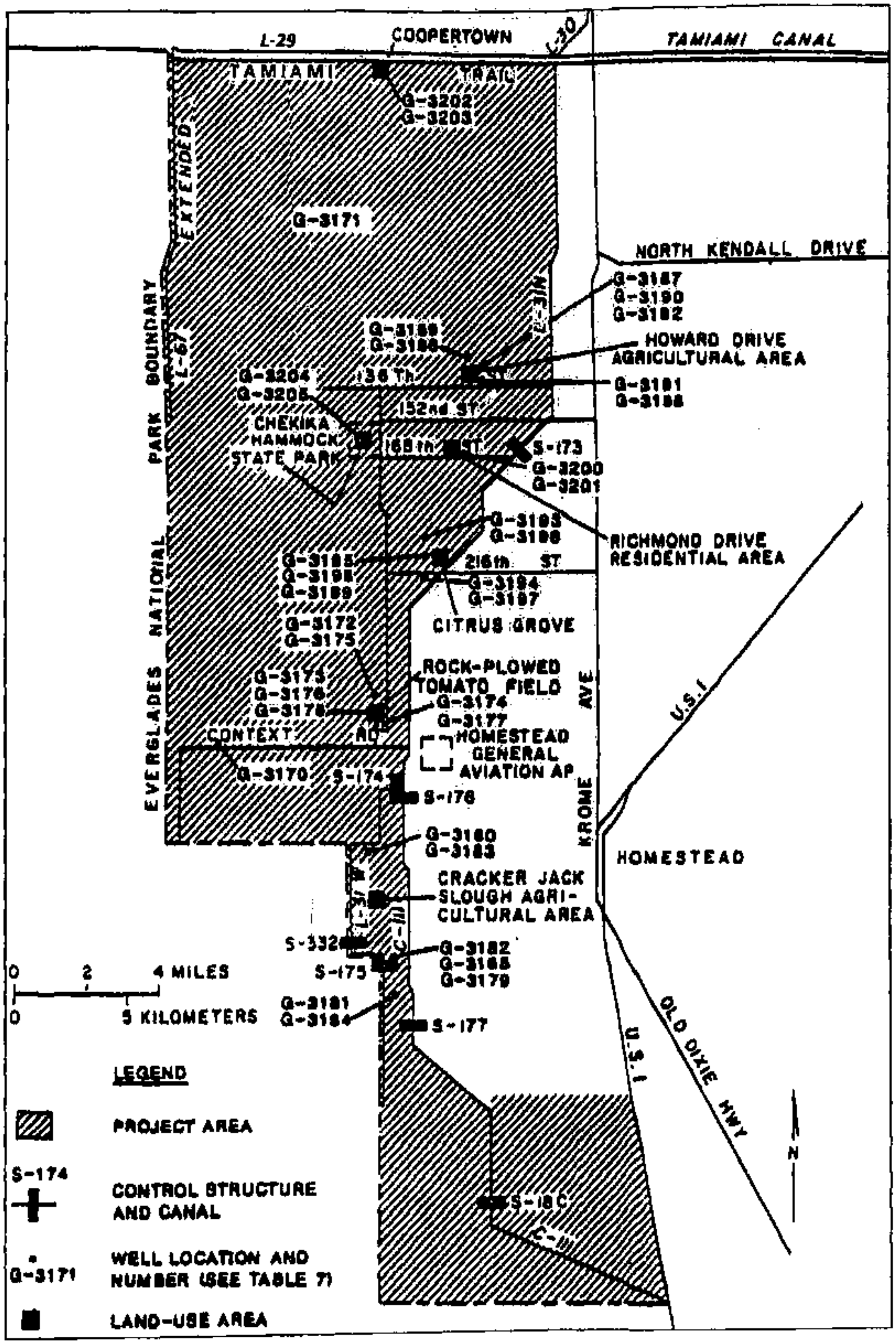
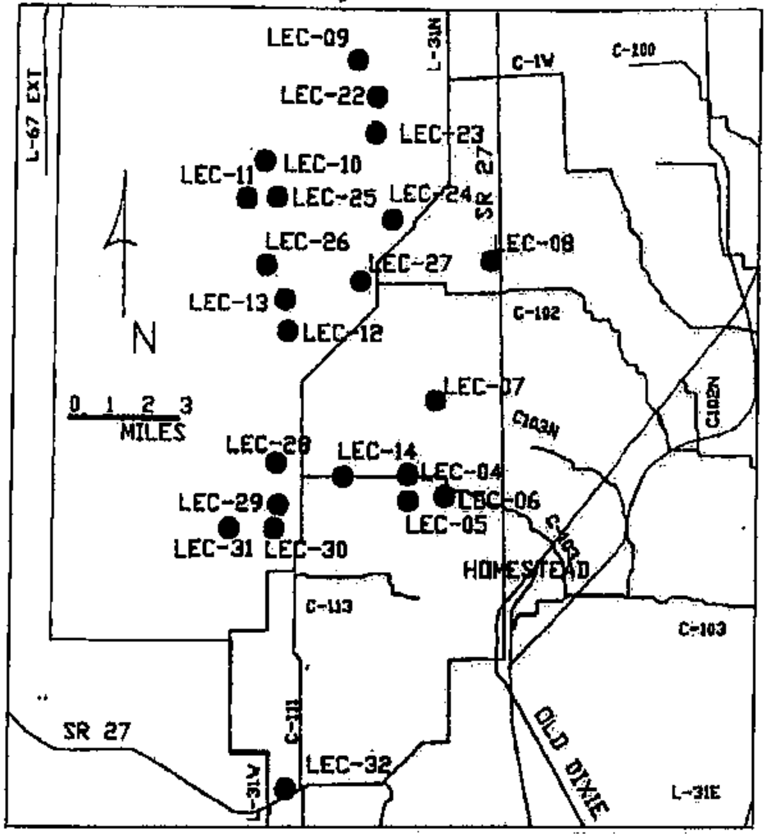


Figure 66. Groundwater Monitoring Locations of the South Dade Agricultural Pilot Study.



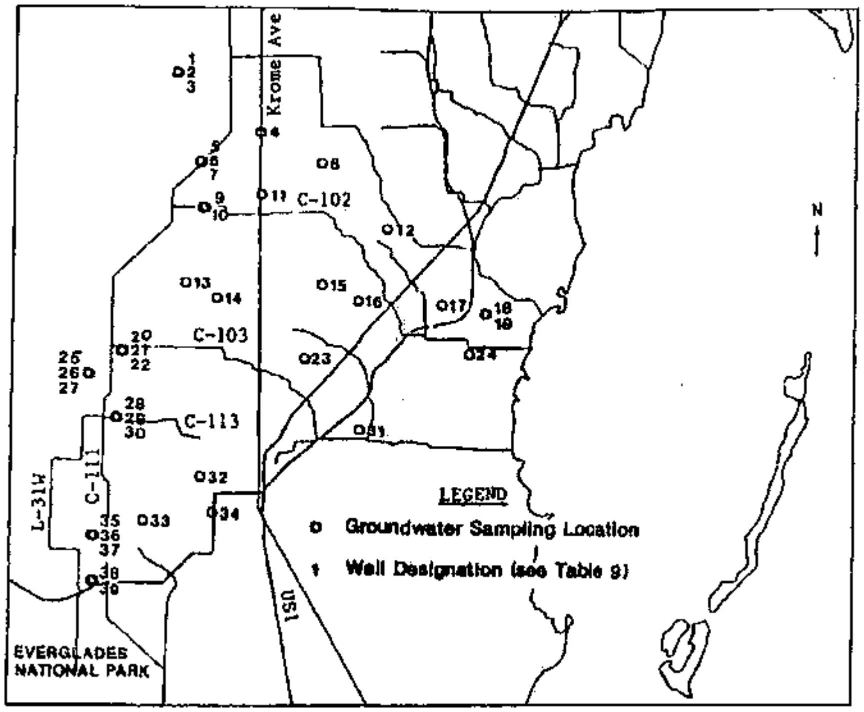
Source: Anderson, 1986

Ground water can move relatively long distances under low hydraulic gradients through the cavernous zones; but movement is retarded by zones characterized by dense limestone and fine sand. In central and south Dade County, hydraulic conductivity, and therefore the transmissivity, is high because of the cavernous limestone, but transmissivities decrease west into the ENP due to a thinning of the aquifer. The regional ground water flow gradient is seaward, but may be locally influenced by drainage canals and major municipal well fields.

Coupling of Ground Water and Surface Waters. In the agricultural area of south and central Dade County, irrigation wells are usually rotary drilled to depths of 25 to 35 feet. Wells are drilled at spacings of as little as 300 feet and casing is not required (Klein and Hull, 1978). Typically, truck-mounted irrigation pumps are moved from well to well for crop irrigation. Each well is pumped for short periods at rates of 500 to 1,000 gallons per minute (gpm) (Klein and Hull, 1978). Metro-Dade County DERM (1989) has completed a preliminary study of these wells in conjunction with pesticide/herbicide mix loading activities (**Table 73**). Results of this work indicated the presence of carbophenothion, chlorothalonil, malathion, methomyl, oxamyl, and high levels of endosulfan and parathion (ethyl) (DERM, 1989). This same study detected various classes of metals including copper, manganese, and zinc at parts per million levels.

Groundwater Contamination with Agricultural Chemicals. The issue of possible contamination of groundwater by agricultural chemicals, via unlined and uncapped wells, has been a continuing concern in South Dade County and has not

Figure 67. Groundwater Monitoring Locations of the DERM Chlorinated Pesticide Study.



Source: Baker, 1988

Table 69. Well Locations of USGS Land Use/Water Quality Studies (Waller, 1983).

Site	USGS Well Number	Depth (feet)	Source
Baseline Wells	G-3186,-3189,-3172, -3175,-3180,-3183	10-27	Waller, 1983
Northeast Shark River Slough	G-3171	12	Waller, 1981
Context Road at Bridge 27	G-3170	12	Waller, 1981
Howard Drive Agricul. Area	G-3187,-3188,-3190, -3191,-3192	10-41	Waller, 1983
Citrus Grove	G-3193 to -3199	11-46	Waller, 1983
Rock-plowed Tomato Field	G-3173,-3174,-3176, -3178	10-41	Waller, 1983
Cracker Jack Slough Agricul. Area	G-3179,-3181,-3182, -3184,-3185	10-39	Waller, 1983
Coopertown	G-3202,-3203	10-34	Waller, 1983
Richmond Drive Resid. Area	G-3200,-3201	11-42	Waller, 1983
Chekika Hammock State Park	G-3204,-3205	14-44	Waller, 1983

Table 70. Well Locations for the South Dade Agricultural Pilot Study.

SFWMD Sample Station	Latitude	Longitude	USGS Well
LEC 04	25° 30' 56"	80° 30' 53"	C103(6A)
LEC 05	25° 30' 58"	80° 30' 53"	C103(1)
LEC 06	25° 30' 29"	80° 29' 66"	S196A
LEC 07	24° 32' 33"	80° 30' 10"	G-1353
LEC 08	25° 35' 37"	80° 28' 44"	G-757A
LEC 09	25° 39' 53"	80° 32' 14"	G-3272
LEC 10	24° 37' 44"	80° 34' 36"	G-3273
LEC 11	25° 36' 56"	80° 35' 03"	G-1502
LEC 12	24° 34' 45"	80° 34' 03"	200 ST
LEC 13	25° 34' 45"	80° 34' 03"	200 ST
LEC 14	25° 30' 42"	80° 29' 40"	C103(12A)
LEC 22	25° 39' 07"	80° 31' 43"	G-3189
LEC 23	25° 38' 42"	80° 31' 43"	G-3187
LEC 24	25° 36' 30"	80° 31' 18"	G-3201
LEC 25	25° 36' 56"	80° 35' 03"	G-3204
LEC 26	25° 35' 30"	80° 34' 32"	G-3124
LEC 27	25° 35' 10"	80° 32' 07"	G-3198
LEC 28	25° 31' 12"	80° 34' 15"	G-3175
LEC 29	25° 30' 18"	80° 34' 12"	G-3177
LEC 30	25° 29' 48"	80° 34' 18"	G-3117
LEC 31	25° 29' 48"	80° 35' 27"	Recorder
LEC 32	25° 24' 13"	80° 33' 58"	G-3184

Source: Anderson, 1986

Table 71. Well Locations and Surrounding Land Use for the DERM Chlorinated Pesticide Survey.

Station Number*	Well Number	Predominant Land Use in Area
1	G-3188a	Fallow field, Latin vegetation
2	G-3189a	Fallow field, Latin vegetation
3	16-1Cc	Fallow field, Latin vegetation
4	G-3373a	Fallow field, Latin vegetation
5	W-1Ab	Row crops
6	W-1Bb	Row crops
7	W-1Cb	Row crops
8	G-1362a	Groves
9	E-1Ab	Mango groves
10	E-1Bb	Mango groves
11	G-757a	Row crops, ornamentals
12	G-3371a	Lime grove
13	G-3108a	Avocado and lime grove, Row crops
14	G-1363a	Nursery, horse farm
15	G-614a	Avocado grove, residential
16	G-3364a	Lime and avocado grove
17	G-3370a	Row crops, nursery
18	G-3412a	Nursery
19	S-68c	Nursery
20	E-2Ab	Lime grove (N of canal), Row crops
21	E-2Bb	Lime grove (N of canal), Row crops
22	E-2Cb	Lime grove (N of canal), Row crops
23	G-3165a	Avocado grove
24	G-3169a	Nursery
25	G-3174a	Mango groves, natural vegetation
26	G-3177a	Mango groves, natural vegetation
27	21-3Cc	Mango groves, natural vegetation
28	E-3Ab	Row crops
29	E-3Bb	Row crops
30	E-3Cb	Row crops
31	G-3368a	Row crops, citrus
32	G-3360a	Row crops, citrus
33	G-3359a	Row crops
34	G-3864a	Aqueduct Authority, Residential
35	W-4Ab	Row crops
36	W-4Bb	Row crops
37	W-4Cb	Row crops
38	G-3181a	Row crops
39	G-3184a	Row crops

[a] U.S. Geological Survey Well
[b] District Well
Source: Baker, 1988

Table 72. Summary of Positive Pesticide Monitoring Data for Groundwater.

Site (Study)	Pesticides at or above detection limit: Detected once	Detected twice
South Dade Agricultural Pilot Study	(Anderson, 1986)	
LEC-04 *n=1	Aldrin	
LEC-05 n=1	Aldrin	
LEC-06 n=1		
LEC-07 n=1	Aldrin	
LEC-08 n=1	Aldrin, Methoxychlor	
LEC-09 n=1	Aldrin	
LEC-10 n=1		
LEC-11 n=1		
LEC-12 n=1		
LEC-13 n=1	Aldrin	
LEC-14 n=1	alpha-BHC, DDT, Dieldrin	
DERM Chlorinated Pesticide Study	(Baker, 1988)	
1(G-3188) n=3	Dieldrin	Heptachlor
2 (G-3189) n=3	Dieldrin, Heptachlor	
3 (16-C) n=3	DDE, DDD, DDT, Dieldrin	
4 (G-3373) n=3	Aldrin, Lindane, DDE, Dieldrin	
5 (W-1A) n=3	Lindane, DDT, Endosulfan	
6 (W-1B) n=3	Lindane, Heptachlor epoxide	
7 (W-1C) n=3	Endosulfan, Heptachlor	
8 (G-1362) n=3	Lindane, DDE	
9 (E-1A) n=3		
10 (E-1B) n=3	Lindane, Heptachlor epoxide	
11 (G-757A) n=3	Aldrin, Dieldrin	
12 (G-3371) n=3	DDE	
13 (G-3108) n=3	DDE, DDT, Dieldrin	
14 (G-1363) n=3	Lindane	Chlordane
15 (G-614) n=3	DDE, Dieldrin	
16 (G-3364) n=3	Lindane, Chlordane, DDT, Endrin	
17 (G-3370) n=3	DDE, Dieldrin, Endosulfan	
18 (G-3412) n=3	Aldrin, Dieldrin, Endrin, Heptachlor	
19 (S-6B) n=3	Aldrin, Endrin, Heptachlor	
20 (E-2A) n=3	Lindane, DDE, Dieldrin, Heptachlor epoxide	Heptachlor
21 (E-2B) n=3	DDE, Endrin, Heptachlor, Heptachlor epoxide	
22 (E-2C) n=3	Aldrin, Heptachlor, Heptachlor epoxide	
23 (G-3365) n=3	Aldrin, Lindane, Chlordane, DDE, DDT, Dieldrin, Endosulfan	
24 (G-3369) n=3	Heptachlor, Heptachlor epoxide	
25 (G-3174) n=3	DDE, Heptachlor epoxide	Heptachlor
26 (G-3177) n=3	Aldrin, Chlordane, DDE, Endrin, Heptachlor epoxide	
27 (21-3C) n=3	Aldrin, Endrin, Heptachlor	
28 (E-3A) n=3	Endrin, Heptachlor epoxide	
29 (E-3B) n=3	Endosulfan, Heptachlor	
30 (E-3C) n=3	Lindane, Heptachlor epoxide	
31 (G-3368) n=3	Lindane	
32 (G-3360) n=3	Aldrin, Lindane, Chlordane Endrin, Heptachlor, Heptachlor epoxide	
33 (G-3359) n=3	DDT, Dieldrin	
34 (G-864) n=3	Lindane, DDE, Dieldrin, Heptachlor	
35 (W-4A) n=3	Aldrin, Lindane, DDE, Dieldrin, Heptachlor epoxide	Heptachlor
36 (W-4B) n=3	Chlordane, DDE, Heptachlor, Heptachlor epoxide	Aldrin, Lindane
37 (W-4C) n=3	DDE, DDT, Endrin, Heptachlor epoxide	Endosulfan
38 (G-3181) n=3	Lindane, DDE, Heptachlor, Heptachlor epoxide	
39 (G-3184) n=3	Lindane, DDE, Dieldrin, Heptachlor	

* n = total number of samples collected
Data provided in Appendix C
Source: DERM, 1989

Table 73. Mixed-Loading Well Water Quality Survey: Pesticide Residues and Metals --Concentrations in µg/l).

Site	Carboph **(0.1)	Chlrthl (0.1)	Endsfn (0.042)	Malath (0.06)	Methml (20.0)	Oxamyl (2.0)	Parath (0.6)	Cu (2.0)	Mn (1.0)	Zn (3.0)
1	BDL*	BDL	9	BDL	BDL	BDL	BDL	60.5	51.0	22.6
1 Dupl	-	-	8	-	-	-	-	67.0	69.0	19.9
2	BDL	BDL	18	BDL	BDL	BDL	0.14	9.0	47.4	21.8
2 Dupl	-	-	12	-	-	-	-	6.6	37.2	21.1
3	BDL	BDL	179	BDL	159	BDL	BDL	950	1110	202.0
3 Dupl	-	-	217	-	138	-	-	1050	1230	211.5
4	BDL	65	63	BDL	BDL	BDL	0.20	1000	390	97.5
4 Dupl	-	12	77	-	-	-	0.25	950	360	96.5
4 Blank	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
5	BDL	5	11	BDL	21	BDL	BDL	340	150	44.1
5 Dupl	-	5	10	-	16	-	-	330	130	32.8
6	BDL	BDL	0.1	BDL	BDL	BDL	BDL	38.8	BDL	41.4
6 Dupl	-	-	0.1	-	-	-	-	43.4		44.8
7	0.6	BDL	530	BDL	BDL	529	0.21	6.2	8110	980.0
7 Dupl	0.4	-	740	-	-	1192	0.25	4.4	7950	920.0
8	BDL	BDL	0.6	BDL	17	BDL	BDL	89.5	170	71.2
8 Dupl	-	-	1.2	-	BDL	-	-	147	240	89.8
9	BDL	BDL	81	BDL	BDL	58	0.5	5570	990	107.4
9 Dupl	-	-	65	-	-	49	0.3	4380	830	98.7
10	6.1	BDL	11560	4	BDL	BDL	1.0	16440	2840	1160
10 Dupl	1.7	-	10452	5	-	-	0.8	16580	2740	1110
11	BDL	87	920	BDL	BDL	215	1773	230	2930	430
11 Dupl	-	23	580	-	-	226	519	300	3790	560
12	BDL	14	217	1	BDL	22	1325	770	570	75.0
12 Dupl	-	8	263	0.4	-	21	493	650	460	67.8

Source: Metro Dade County DERM, 1989

Residues detected include: carbophenothion, chlorothalonil, endosulfan (reported as sum of I, II, and sulfate), malathion, methomyl, oxamyl, and parathion (ethyl).

Other residues tested for but not detected include: benomyl, chlorpyrifos, diazinon, dicofol, guthion, methamidophos, metribuzin, and mevinphos.

* BDL = Below detection limit

- = Not analyzed

been adequately investigated. Dade County has an ongoing monitoring program that should address this issue by sampling surface water and groundwater in the proximity of mixing wells and in conjunction with areal applications of pesticides and fertilizers. Data concerning this problem could form the basis for permitting decisions concerning surface water and ground water resources. In addition, the county should assess the impacts of abandoned shallow wells in areas that have subsequently shifted to urban development. Consideration should be given to requiring capping and lining of new wells in south Dade County, and retrofitting old wells, if possible, with caps and liners. Currently there is little coordinated effort to establish the link between contamination of surface waters and groundwater. The fact that observable levels of contamination occur in monitoring wells, indicates that these compounds apparently can move readily through the estimated 15,000 unlined, uncapped wells in south Dade County into ground water (DERM, 1989).

Few studies have examined the breakdown products of pesticides, determined their persistence in the Everglades environment, and evaluate their effects on' and accumulation in, native flora and fauna. It is important also to begin to evaluate the toxicity, bioaccumulation and fate of adjuvants (compounds used as carrier solvents for the active ingredients in pesticides). These compounds are listed as inert ingredients, are unregulated, and may be more toxic that the active ingredient

(Ghassemi, *et al.*, 1982). It is also critical to know the ultimate fate of agricultural and urban contaminants in surface and ground waters since these waters ultimately move into the marine systems of Biscayne Bay, Barnes Sound, Crocodile Lake National Wildlife Refuge, Northeast Florida Bay and John Pennekamp State Park.

4. Biotic Resources

Biological Resources within the East Everglades. The East Everglades Area contains a variety of vegetation communities. Beard (1938) described the East Everglades - Shark River Slough region as Everglades Prairie indicating that unlike other areas of the Everglades, sawgrass was not the most common grass (sedge) found, but that switch grass (*Spartina bakeri*, Merr.) was the dominant vegetation present as a result of alteration of the natural system by drainage and fire.

The following authors have compiled inventories of various parts of the Shark Slough-East Everglades system: Hofstetter and Hilsenbeck,1980; Gunderson, 1989; Herndon and Sternberg, 1987; Molnar and Bernardino, 1988; and Wood and Tanner, 1989. Vegetation patterns in this region are a function of a variety of factors including fire, hydroperiod, hydropattern, soil composition, and availability of seed source for colonization/re-colonization (Hofstetter and Hilsenbeck, 1980; Gunderson, 1989). Community types found within the EEA and their hydrologic requirements are listed in **Table 74.**

Table 74. Major Vegetation Community Types within the East Everglades / C-111 Planning Area as Defined by Hydroperiod Characteristics.

Community Type	Range of Hydroperiods (months)	Range of mean Hydroperiods (months)	Mean of primary type	Hydric Category
1) Mosaic *Eleocharis* & *Rhynchospora* dominant	3.9 - 12	6.9 - 10.3	10.3	semi permanent
2) Mosaic - *Cladium* dominant	3.9 - 12	6.9 - 10.3	9.6	semi permanent
3) Mosaic - marsh thicket	6.5 - 9.2	8.6 - 9.6	9.6	semi permanent
4) *Salix* - *Annona* - *Myrica* thicket	1.0 - 10.7	8.0	-	long seasonal
5) *Typha* thicket	3.0 - 12	9.3	-	semi permanent
6) *Salix* thicket	4.1 - 12	5.3	-	long seasonal
7) Mosaic - *Muhlenbergia*/ *Andropogon*	1.0 - 4.3	2.6	-	mesic
8) Bayhead forest	< 3.0	< 3.0	-	mesic
9) Mosaic - *Muhlenbergia*/ *Cladium*	1.0 - 12	2.6 - 10.3	3.0	short
10) *Chrysobalanus* thicket	4.0 - 5.0	4.0 - 5.0	-	short seasonal
11) Post-burn bayhead	< 3.0	< 3.0	-	mesic
12) *Melaleuca* forest	-	-	-	**
13) Successional bayhead forest	< 1.0	< 1.0	-	ephemeral

Source: Modified from: Molnar and Bernardino, 1988

** Hydroperiods of Melaleuca stands vary depending upon the particular community that has been colonized. However, short seasonal wetlands are more susceptible to Melaleuca colonization than long seasonal wetlands.

Plant communities found within this region are similar to those found in Shark Slough in ENP. Communities have been grouped by several authors. The following six broad categories were used by the East Everglades Resources Planning project in 1980:

1) Hammock forest (tropical and broadleaf tree);
2) Thicket (cocoplum-willow, wax myrtle-salt bush, buttonwood, pond apple, scrub mangrove);
3) Prairie (muhly, sawgrass, beardgrass);
4) Marsh (sawgrass, spike rush-beak rush, maidencane, flag-pickerel weed, cattail);
5) Prairie - tree island mosaic;
6) Disturbed (including native and exotic species).

Molnar and Bernardino (1988), characterized the following communities after those described by Hofstetter and Hilsenbeck (1980):

"*Graminoid mosaics* - hydric flats interspersed with sawgrass marshland. In dryer areas, hydric flats and sawgrass marshes are replaced by more mesic associations dominated by muhly grasses and broomsedges. The relative dominance of graminoid type appears to be related to the degree of wetness along a northwest-southwest gradient in the slough." Graminoid mosaics include communities 1, 2, 7, and 9 on **Table 74.**

"*Woody thickets* - Generally these dense stands of hydric shrub and small tree species occur adjacent to tree islands or within open marshlands adjacent to seasonal ponds." Includes communities 4, 6, and 10 on **Table 74.**

"*Marsh thicket mosaics* - Consisting of sawgrass marsh flats, semi-open water zones and woody thickets occurring in close proximity to one another (*sic*). Considered by Hofstetter and Hilsenbeck (1980) to be a result of 'hummocky' differentials in elevation over limited areas as a result of past fire disturbances. They often occur in association with tree islands." Community 3 of **Table 74.**

"*Tree islands* - Various successional stages (including post-burn stages) of closed canopy hydric and mesic tree stands that ultimately can become tropical hammock forests." Includes communities 8, 11, and 13 of **Table 74.**

"*Exotic communities* - Generally *Melaleuca* invaded phases of any of the above communities, representing deflected serial sequences."

Slough communities are often found in association with forested tree islands and are generally the wettest of areas (Gunderson and Loftus, 1989 in press). The rocky glades is primarily comprised of thinly scattered sawgrass on marl soils in association with muhly prairies.

Habitats that occur in the East Everglades include the slough and long hydroperiod wetlands or the rocky glades and associated short hydroperiod wetlands (**Figure 68**). Hydroperiods of regions within the heart of the slough regulate the deposition of the high organic peat soils or the precipitation of less productive marl soils which form under shorter hydroperiod lengths (Gunderson, 1987; Hofstetter and Hilsenbeck, 1980). The deposition of peat soils requires longer hydroperiods and extended inundation and is generally characteristic of systems that dry only under

Figure 68. Successional Sequences of Everglades Vegetation in the East Everglades Based on Hydroperiod Relationships

SEMI-PERMANENT WETLANDS (9 - 12 months)
1) *Eleocharis/Rhynchospora* dominant mosaic
2) *Cladium* dominant mosaic
3) Marsh thicket mosaic
4) *Typha* thicket

↓

LONG SEASONAL WETLANDS (5 - 9 months)
1) *Salix/Annona/Myrica* thicket
2) *Salix* thicket

↓

SHORT SEASONAL WETLANDS (3 - 5 months)
1) *Muhlenbergia/Cladium* mosaic
2) *Chrysobalanus* mosaic

↓

MESIC WETLANDS (1 - 3 months)
1) *Muhlenbergia/Andropogon* mosaic
2) Bayhead forest
3) Post-burn bayhead

↓

EPHEMERAL WETLANDS (< 1 month)
1) Successional bayhead

Source: Simplified successional sequences based on hydroperiod relationships modified from Molnar and Bernardino, 1988

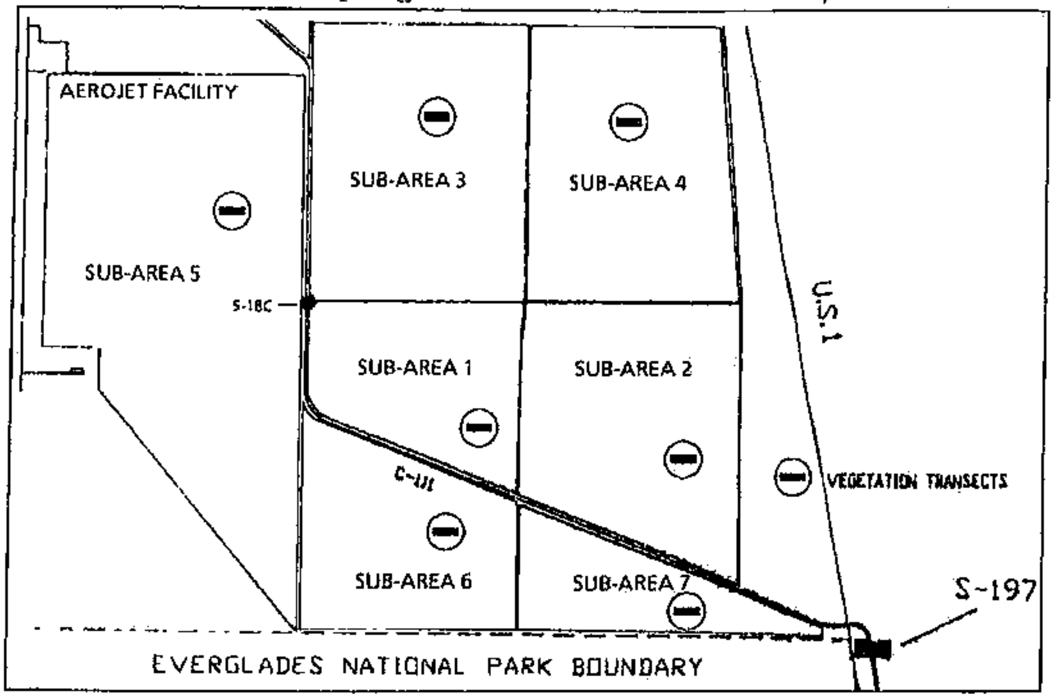
severe conditions (Leach *et al.* 1972). The productivity of these soils is related to their function in the food chain and the refuge that they provide for fish and invertebrates during dry periods (Loftus *et al.* 1986, in press; Loftus and Kushlan, 1987).

In 1987-88 a reassessment of the exotic tree species *Melaleuca quinquenervia* was made for this area by the Metro-Dade County Department of Environmental Resources Management (DERM). This analysis showed a dramatic increase in the extent of infestation. Densities for the same sites examined in both 1978 and 1985 showed 3 and 6 trees per site in 1978 and 46 and 170 trees per site in 1985 (Molnar and Bernardino, 1988). Since 1985 there has been an acceleration of the rate of colonization by this species in the south Dade region (Discussion with G.Molnar, 1989, DERM). In addition, there has been a series of fires since 1988 that have occurred in the East Everglades Area and in bordering wetlands to the northeast and to the east. These fires may further stimulate production of Melaleuca saplings and seeds and thus enhance existing threats to regional ecosystems and water supplies.

Biological Resources within the C-111 Basin. Marshes of the C-111 system south of Florida City include a variety of habitats. These marshes are physiographically classified as southern coastal glades and are also known as transverse or finger glades (Hoffmeister, 1974; Schomer and Drew, 1982). Mid and southern marsh vegetation is composed primarily of sawgrass (*Cladium jamaicense*) and spikerush (*Eleocharis cellulosa*) prairies that grade into stunted mangroves, primarily the red mangrove (*Rhizophora mangle*) and the black mangrove (*Avicennia* *germinans*) (SFWMD 1990). The northern marsh is primarily dominated by muhly grass (*Muhlenbergia* sp.) and the entire area contains bayheads, willows, and hardwood hammocks (SFWMD, 1990). In addition a large portion of this area was historically pineland with some relict pineland areas left around Florida City.

Periphyton Communities. An important habitat in Everglades ecosystems are the periphyton communities associated with marl soils and sediments. Areas sampled by the SFWMD (1990) are shown in **Figure 69**. Periphyton communities in these areas are dominated by two species of filamentous

Figure 69. SFWMD Sampling Locations in the C-111 Basin, 1985-1987.



Source: SFWMD, 1990.

blue green algae, *Scytonema hofmannii* and *Schizothrix calcicola*. Other algae that colonized artificial substrates during this study included the diatoms: *Cymbella ruttneri, Mastogloia smithii v. lacustris, Anomoeneis vitrea, Synedra pahokeenis, Achnanthes minutussuma, Nitzschia* (7 sp), and *Nitzschia denticula v. elongata.* Filamentous green algae occasionally observed were; *Mougeotia spp., Bulbochaetae spp.*, and *Spirogyra Spp.* Low numbers of the desmid species, *Pleurotaenium minutum, Cosmarium* sp., *Gonatozygon* spp., and *Desmidium* spp. were also observed. Previous work in the northern Everglades WCAs and ENP has statistically documented that these assemblages of algae are reliable indices of low nutrient, alkaline, hard water conditions and, as such, they indicate that relatively pristine water quality conditions probably exist in the lower portions of the C-111 system (Swift and Nicholas, 1987; SFWMD,1990).

Macroflora. Of the 40 species of plants counted along transect lines by the SFWMD (1990) only two, sawgrass (*Cladium jamaicensis*) and spikerush (*Eleocharis cellulosa*) were present at all transect sites. Sub-areas with relatively low diversity were 1, 2, 6, and 7 while sub-areas with high diversity were 3, 4, and 5 (**Figure 69**). Plants found in this study are listed in **Table 75**. This study concluded that various sections of the C-111 marsh appeared to be greatly influenced by hydroperiod. Short hydroperiod marshes in the northern end of the system were dominated by muhly grass (*Muhlenbergia* sp.) and had experienced extensive encroachment of wax myrtle (*Myrica cerifera*), brazilian pepper (*Schinus terebinthifolius*) and australian pine (*Casuarina* Sp.). Sub-area 5, located in to the west of C-111, appeared to be the most affected by shortened hydroperiod and contained large numbers of terrestrial species. The longer hydroperiod that occurred in the south end of the system was probably responsible for the sawgrass community found in the impounded the area formed by C-109 and C-110. (SFWMD, 1990).

Fauna. Fishes found in the East Everglades/C-111 basin are listed in **Table 76**. Fifteen species of fish were collected by the SFWMD (1990). The flagfish (*Jordanella floridae*) and the mosquito fish (*Gambusia affinis*) comprised 64% of the fish sampled in this work. Other fish collected in this study were *Lucania goodei, Fundulus chrysotus, Fundulus confluentus, Fundulus seminolis, Heterandria formosa, Fundulus grandis, Poecilia latipinna, Ictalurus natalis, Fundulus sp., Lepomis gulosus, Etheostoma fusiforme, Lepomis macrochirus, Cyprinodon variegatus*, and *Lepomis microlophus*. The primary aquatic invertebrates of this region are shrimp (*Palaemonetes paludosus*) and crayfish (*Procambarus alleni*). Most invertebrates, especially insects, have not been studied in detail. General descriptions of invertebrates and insects are given in the ENP section of this report.

Hydroperiod is critically important to the production of fish and invertebrates. A reservoir of breeding fish is required to seasonally colonize short-period wetlands as they are created. Once these wetlands dry, fish become increasingly concentrated in pools and serve as food for foraging birds (Ogden personal communication; Loftus and Kushlan, 1987). Extremely dry conditions and rapid drying rates result in high densities of fish concentrated in refuge pools because of their inability to normally move to, or due to the loss of connections to, more permanent wetlands. This situation often favors fish kills (Kushlan, 1974; Loftus and Kushlan , 1987; Loftus *et al.*, 1986).

The C-111 basin is used extensively by migrant wading birds as forage habitat (Powell, *et al.*, 1989a). Hydrologic conditions, fluctuating water levels and extended hydroperiod marshes combine to provide excellent forage habitat for feeding. Several species of rare and endangered birds utilize or historically utilized this area including; roseate spoonbills (*Ajaia ajaja*), the Cape Sable sparrow (*Ammospiza maritima mirabilis*), little blue heron (*Egretta caerulea*), great egret (*Casmerodius albus*), snail kite (*Rostrhamus sociabilis*), tri-color heron (*Egretta tricolor*), snowy egret (*Egretta thula*), white ibis (*Eudocimus albus*), white crowned pigeon (*Columba leucocephala*), wood stork (*Mycteria americana*), bald eagle (*Haliaeetus leucocephalus leucocephalus*), southeastern American kestrel (*Falco sparverius paulus*) least tern (*Sterna albifrons*) and the Florida sandhill crane (*Grus canadensis pratensis*). This area including that portion to the east of U.S. Highway 1, is particularly important as forage habitat for the roseate spoonbill (*A. ajaja*) Powell, *et al.*, 1989a; Powell and Bjork, 1989) (**Figure 70**).

Herpetofauna found in the East Everglades /C-111 system follow the same general distributions that occur in the southern Everglades . Important species include the American alligator (*Alligator mississippiensis*), eastern indigo snake (*Drymarchon corais couperi*), mangrove water snake (*Natrix fasciata compressicauda*), the mangrove terrapin (*Malachlemys terrapene rhizophora*), freshwater turtle species (*Chrysemys* sp.), and potentially five species of sea turtles (*Caretta caretta, Dermochelys coriacia, Chelonia mydas, Eretmochelys imbricata* and *Lepidochelys kempi*) in Barnes Sound (Duellman and Schwartz, 1958). This region is known breeding habitat for American crocodiles (*Crocodylus acutus*), with two of the

Table 75. Mean % Cover and (Frequency of Occurrence) of Vegetation in the Seven Sub-Areas at C-111

SPECIES	1	2	3	4	5	6	7
Cladium jamaicensis	16.7(100)	11.6(100)	14.3(100)	8.7(100)	9.4(100)	14.6(100)	20.5(100)
Eleocharis cellulosa	19.5(96)	15.6(78)	0.5(30)	<0.1(10)	0.5(20)	19.8(98)	18.8(86)
Rhynchospora tracyi	<0.1(2)	-	<0.1(4)	0.1(12)	0.9(64)	<0.1(2)	<0.1(4)
Utricularia sp.	-	-	0.2(14)	-	0.5(24)	0.6(70)	11.0(100)
Rhynchospora microcarpa	<0.1(6)	-	<0.1(4)	0.4(86)	3.4(90)	<0.1(8)	-
Crinum americanum	-	-	<0.1(6)	-	<0.1(2)	0.2(22)	<0.1(2)
Rhizophora mangle	0.1(12)	0.1(18)	-	-	-	-	-
Aster tenuifolius	-	-	<0.1(10)	0.2(40)	0.2(40)	<0.1(2)	-
Panicum tenerum	-	-	<0.1(6)	0.1(12)	0.4(84)	-	-
Eragrostis elliotti	-	-	0.1(8)	<0.1(6)	0.4(70)	-	-
Andropogon virginicus	-	-	0.1(8)	<0.1(4)	0.3(54)	-	-
Bulbostylis ciliatifolia	-	-	<0.1(2)	<0.1(2)	<0.1(10)	-	-
Pluchea sp.	-	-	-	<0.1(4)	<0.1(2)	<0.1(8)	-
Schoenus nigricans	0.1(4)	-	-	11.9(72)	26.9(67)	-	-
Aristiola simpliciflora	-	-	-	0.1(26)	0.3(56)	-	-
Muhlenbergia capillaris	-	-	<0.1(10)	-	<0.1(4)	-	-
Ludwigia alata	-	-	<0.1(8)	-	0.1(16)	-	-
Solidago sempervirens	-	-	-	<0.1(6)	<0.1(6)	-	-
Eupatorium leptophyllum	-	-	<0.1(4)	<0.1(2)	-	-	-
Sagittaria lancifolia	-	-	<0.1(2)	-	<0.1(4)	-	-
Cuscuta sp.	-	-	-	-	0.2(44)	-	-
Rhynchospora divergens	-	-	-	-	0.2(38)	-	-
Proserpinaca palustris	-	-	<0.1(2)	-	<0.1(6)	-	-
Oxypolis filiformis	-	-	-	-	<0.1(6)	0.1(2)	-
Rhynchospora inundata	0.4(4)	-	-	-	-	-	-
Utricularia cornuta	-	-	-	-	<0.1(4)	-	-
Utricularia subulata	-	-	<0.1(4)	-	-	-	-
Chara sp.	-	<0.1(12)	-	-	-	-	-
Juncus sp.	0.1(12)	-	-	-	-	-	-
Bacopa caroliniana	-	-	<0.1(6)	-	-	-	-
Peltandra sp.	-	-	-	-	<0.1(8)	-	-
Conocarpus erectus	-	-	-	0.1(14)	-	-	-
Taxodium distichum	-	-	<0.1(4)	-	-	-	-
Chrysobalanus icacao	-	-	<0.1(2)	-	-	-	-
Persea borbonea	-	-	<0.1(2)	-	-	-	-
Myrica cerifera	-	-	-	<0.1(2)	-	-	-
Mikania scandens	-	-	-	-	<0.1(6)	-	-
Agalinis maritima	-	-	-	-	<0.1(16)	-	-
Cynoctonum mitreola	-	-	-	-	<0.1(2)	-	-
Centella asiatica	-	-	-	-	<0.1(2)	-	-

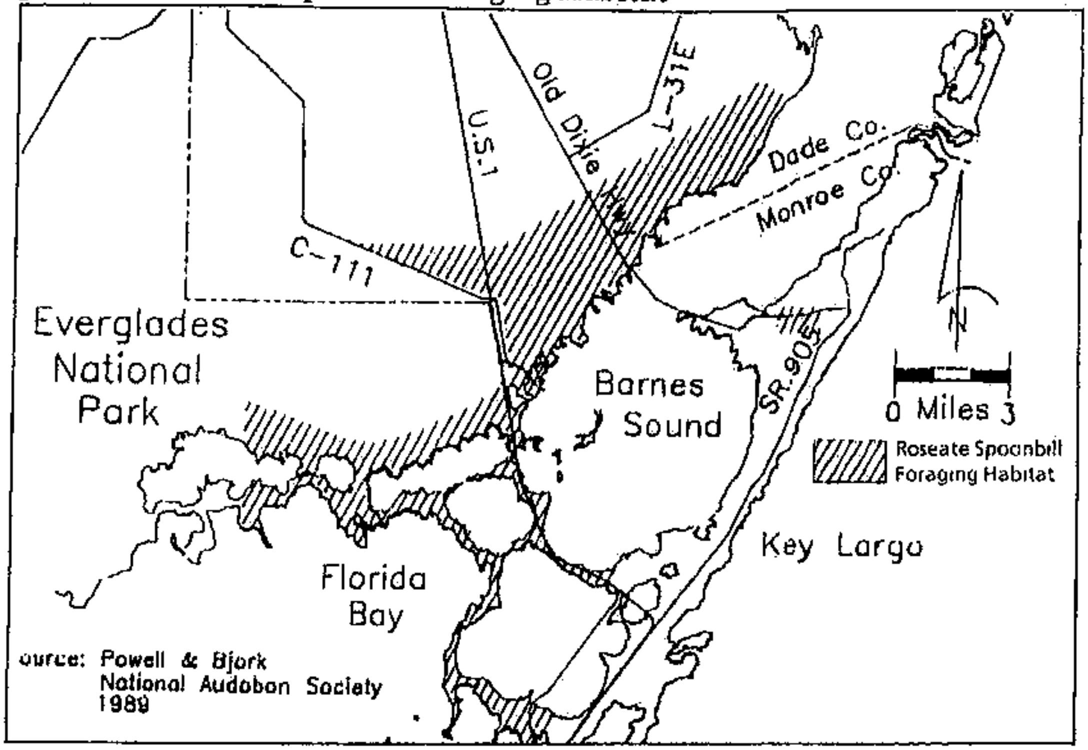
Source: SFWMD,1990

Table 76. Freshwater Fishes of the East Everglades/ C - 111 Basin

Family	Species	Common Name	EEA	C-111
Amiidae	*Amia calva*	bowfin	X	X
Anguillidae	*Anguilla rostrata*	American eel	X	X
Atherinidae	*Labidesthes sicculus*	brook silverside	X	X
Catostomidae	*Erimyzon sucetta*	lake chubsucker	X	X
Centrarchidae	*Elassoma evergladei*	Everglades pygmy sunfish	X	X
	Enneacanthus gloriosus	bluespotted sunfish	X	X
	Lepomis gulosus	warmouth	X	X
	Lepomis macrochirus	bluegill	X	X
	Lepomis marginatus	dollar sunfish	X	X
	Lepomis microlophus	redear sunfish	X	X
	Lepomis punctatus	spotted sunfish	X	X
	Micropterus salmoides	largemouth bass	X	X
Centropomidae	*Centropomus undecimalis*	snook	X	
Cichlidae	*Astronotus ocellatus*	Oscar	X	
	Cichlasoma bimaculatum	black acara	X	X
	Tilapia aurea	blue tilapia	X	X
	Tilapia mariae	spotted tilapia	X	
Clariidae	*Clarias batrachus*	walking catfish	X	X
Cyprinidae	*Notemigonus crysoleucas*	golden shiner	X	X
	Notropis maculatus	taillight shiner	X	X
	Notropis petersoni	coastal shiner		X
Cyprinodontidae	*Adinia xenica*	diamond killifish	X	
	Cyprinodon variegatus	sheepshead minnow	X	X
	Floridichthys carpio	goldspotted killifish		X
	Fundulus chrysotus	golden topminnow	X	X
	Fundulus confluentus	marsh killifish	X	X
	Fundulus grandis	gulf killifish		X
	Fundulus seminolis	Seminole killifish	X	X
	Fundulus lineolatus	lined topminnow	X	
	Fundulus similis	longnose killifish		X
	Jordanella floridae	flagfish	X	X
	Lucania goodei	bluefin killifish	X	X
	Lucania parva	rainwater killifish		X
Elopidae	*Megalops atlanticus*	tarpon	X	X
Esocidae	*Esox niger*	chain pickerel	X	
Gerreidae	*Diapterus plumieri*	striped mojarra		X
Gobiidae	*Lophogobius cyprinoides*	crested goby		X
Ictaluridae	*Ictalurus natalis*	yellow bullhead	X	X
	Ictalurus nebulosus	brown bullhead	X	
	Ictalurus punctatus	channel catfish	X	X
	Noturus gyrinus	tadpole madtom	X	X
Lepisosteidae	*Lepisosteus platyrhincus*	Florida gar	X	X
Mugilidae	*Mugil cephalus*	striped mullet	X	
Percidae	*Etheostoma fusiforme*	swamp darter	X	X
Poeciliidae	*Belonesox belizanus*	pike killifish		X
	Gambusia affinis	mosquitofish	X	X
	Gambusia rhizophorae	mangrove gambusia		X
	Heterandria formosa	least killifish	X	X
	Poecilia latipinna	sailfin molly	X	X

Source: Loftus and Kushlan, 1987.

Figure 70. Roseate Spoonbill Foraging Habitat



Source: Powell and Bjork, National Audubon Society, 1989

three known breeding areas bordering this region (Discussion with Frank Mazzotti, University of Florida Institute of Food and Agricultural Science, Fort Lauderdale, Florida. November, 1989). Mammals of specific interest known from this area or potentially found here are the river otter (*Lutra canadensis*), the Florida panther (*Felis concolor*), Florida manatees (*Trichechus manatus*), and several species of bats (Schomer and Drew, 1982).

Coastal and Estuarine Areas. Coastal and estuarine areas consist of saline marshes along southeastern Dade County, including Barnes Sound, and portions of Northeast Florida Bay. This discussion primarily concerns the coastal saline marshes north of Florida Bay and Barnes Sound. The majority of information on Northeast Florida Bay will be covered in the Florida Bay section of this report. The saline portions of this system are primarily coastal scrub mangrove forest. The northern portion of this area consists of stunted mangrove forest that intergrades to more common mangrove tree heights in the extreme southern portion of the system. Coastal bays, lagoons and sounds are heavily influenced by freshwater runoff and alternate between periods of high salinity during dry conditions to almost freshwater under wet conditions. Although northeast Florida Bay appears to be physically separated from Barnes Sound and has very different bottom sediments and communities, both systems have close hydrologic interconnections.

Shoreline vegetation in this region consists of sawgrass near the freshwater uplands, which intergrades to stunted mangrove habitat. Stunted mangroves are thought to be old healthy trees. Their small size is believed to be due to the nutrient-limited nature of the system (Lugo and Snedaker, 1974). An alternate hypothesis, put forth by Schomer and Drew (1982), attributes the distribution of stunted mangroves to the combined effects of restricted flushing, high evaporation rates and resulting salinity stress on the plants. Stunted mangrove areas are primarily composed of the red mangrove (*Rhizophora mangle*), however other species of mangroves found in these areas include the black mangrove (*Avicennia germinans*), the white mangrove (*Laguncularia racemosa*) and buttonwoods (*Conocarpus erecta*). Submerged vegetation in Manatee Bay consists of approximately 1% widgeon grass (*Ruppia* sp.) 6% shoal grass (*Halodule wrightii*) and 93% turtle grass (*Thalassia testudinum*) (SFWMD, 1990).

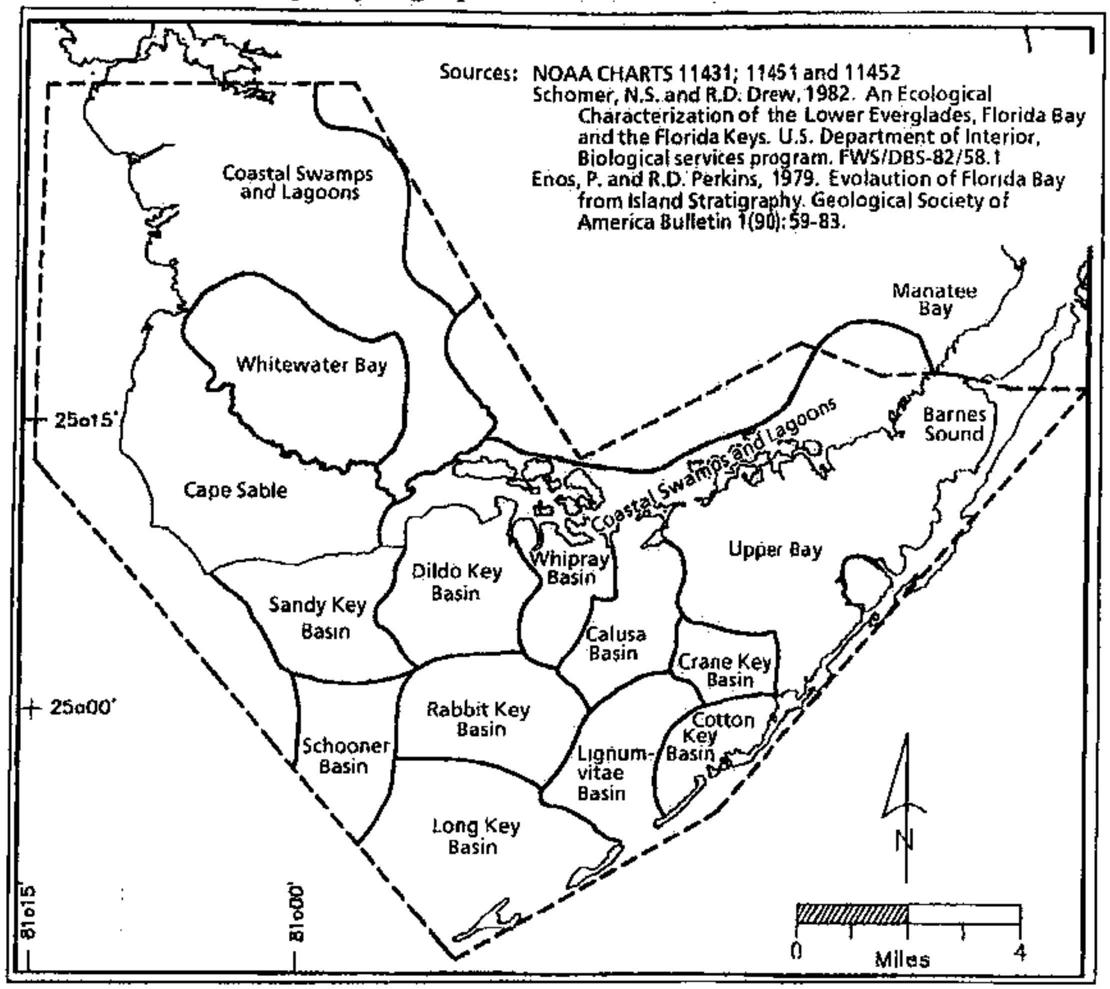
This Page Intentionally Left Blank

G. FLORIDA BAY.

1. Physical Features of Florida Bay and adjacent Coastal Areas.

Major Hydrographic Units. The major hydrographic units within the study area (**Figure 71**) are delineated on the Physiographic Zones and Basins Map. These units can be subdivided into five major physiographic zones shown in **Table 77**.

Figure 71. Florida Bay Physiographic Zones and Basins.



Source: Data Compiled By CSA, Inc.

Table 77. Major Physiographic Features of Florida Bay.

1) The Coastal Swamps and Lagoons; 2) Whitewater Bay; 3) Cape Sable; 4) The Sounds; a) Manatee Bay and Barnes Sound; b) Black Water Sound; c) Little Blackwater Sound; d) Tarpon Basin; e) Little Buttonwood Sound; and f) Buttonwood Sound	5) The Basins of Florida Bay, including: a) Upper Bay; b) Crane Key Basin; c) Calusa Basin; d) Cotton Key Basin; e) Lignumvitae Basin; f) Whipray Basin; g) Rabbit Key Basin; h) Long Key Basin; i) Dildo Key Basin; j) Sandy Key Basin; and k) Schooner Key Basin.

Coastal Swamps and Lagoons. Upland portions of this study area are divided into two drainage basins (U.S. Department of the Interior, 1979), as follows:

1) The Lower Everglades, which drain into the Gulf of Mexico; and
2) Taylor Slough, which drains into Florida Bay.

Coastal swamps and lagoons within the Lower Everglades drainage basin receive runoff from the Shark River Slough and the Broad River/Lostmans River Drainage system (Schomer and Drew, 1982). They are described as reticulate coastal swamps by Davies (1989) and extend upland to the limit of periodic salt water influence. These coastal swamps and lagoons receive most of the surface water runoff from the Everglades National Park. Their present day structure is the result of an evolutionary process dating back to pre-Holocene periods of lower sea levels. At that time, the area influenced by freshwater runoff during the wet season was greater than today, and the flow of this water cut channels and basins into the underlying limestone bedrock. Freshwater inundation also promoted development of extensive peat formations characteristic of the area today. When sea level rose, the more susceptible areas of peat deposits eroded and oxidized, leaving the convoluted system of back bays and tidal creeks seen today (White, 1970; Davies, 1989).

Cottrell (1989) distinguishes two types of coastal swamps and lagoons in the Taylor Slough drainage area. Between West Lake and Seven Palm Lake (to the west of the actual Taylor Slough) there are a series of lakes separated from the coastline referred to as "gulf coastal lagoons." These lakes or lagoons are fringed by mangroves and occasionally hardwoods. South of these enclosed lagoons and along the coastline of Florida Bay are reticulate coastal swamps characterized by higher salinities and dominated by black and white mangrove communities. Buttonwood stands and large prairies of salt tolerant herbaceous vegetation are also characteristic of the area west of Little Madeira Bay. East of Little Madeira Bay, coastal lagoons are absent and surface drainage is better defined. There is also a marked reduction in the presence of buttonwood and herbaceous plant prairies between Little Madeira Bay and Manatee Bay east of Taylor Slough.

Whitewater Bay. Whitewater Bay is the largest and most conspicuous coastal lagoon within Everglades National Park. It receives freshwater from a considerable portion of the Shark River drainage basin, and prior to the construction of Buttonwood Channel, which directly connects Whitewater Bay with Florida Bay, flushing was entirely to the north. The lagoon is confined and created by the presence of the "Cape Sable High," a relict extension of the Atlantic Coastal Ridge, on its southwestern side. The southwest/northeast orientation of the numerous islands within Whitewater Bay suggests historical erosion rates and relict freshwater channeling from periods of lower sea level (Gebelein, 1977).

Cape Sable. Cape Sable is a major geophysical as well as zoogeographic feature on the southwest Florida coast. White (1970) designates this feature as the last westerly remnant of the Atlantic Coastal Ridge, which he calls the Cape Sable High. More recent geophysical investigations in the Gulf of Mexico have indicated a tentative link between these features and submerged features seen at the edge of the west Florida Shelf. Northward from this topographic high, the structure of Florida's western coastline is dominated by rising sea level and freshwater runoff from the Everglades drainage area up to Cape Romano (White, 1970).

Three cape projections form the Cape Sable feature: the Northwest Cape, the Middle Cape, and the East Cape. Sediments along the Northwest and Middle Capes are composed of quartz sand and shell hash characteristic of western Florida beaches north of Cape Romano. From East Cape to Snake Bight, sediments grade into the marls and silts characteristic of Florida Bay (Gebelein, 1977; Roberts *et al.*, 1977). East Cape marks the transition zone from Gulf to Florida Bay sediment regimes. North of the Northwest Cape, in the area of Big Sable Creek, active erosion is taking place due to the lower topography, higher storm surge, increased tidal activity, and greater influence from freshwater runoff. Below this area, the present day beaches of Cape Sable are the surface extensions of the buried coquinoid ledges that form the major portion of Cape Sable's seaward edge.

Behind the beaches is a series of troughs and low dunes dominated by coastal prairie type vegetation. Inland from these prairies, an almost continuous ridge feature supports a coastal hammock vegetative structure (Gebelein, 1977; Schomer and Drew, 1982). Beyond this ridge, Cape topography slopes gradually down toward the Joe River and Whitewater Bay. Within this boggy habitat are a series of troughs that have filled in with peat to form generally east/west trending ponds, the largest of which is Lake Ingraham. Hydrologic conditions within these troughs and ponds may be more or less saline at any given time, depending on local climatological factors.

The Sounds. For the purposes of this report the Sounds, or completely enclosed hydrographic basins at the northeastern end of Florida Bay, are being dealt with as separate entities. Circulation within these water bodies is wind and tide driven except during those time periods, corresponding to the wet season, in which freshwater inflow influences circulation. Hydrologic conditions within these sounds depend on local climatological factors such as rainfall and canal discharge rate. The more northerly sounds such as Long Sound, Little Blackwater Sound, and Manatee Bay lie in what has been called the "Runoff Zone" and are the most influenced by freshwater flow from the mainland. Southern and more westerly sounds such as Blackwater Sound, Tarpon Basin, and Buttonwood Sound lie in what has been called the "Interior Zone" of Florida Bay, and these sounds show the greatest fluctuations in salinities (Ginsburg and Lowenstam, 1958; Schmidt and Davis, 1978).

Geologically, there is a distinction between Manatee Bay and Barnes Sound at the northeastern end of the study area (**Figure 71**), and the rest of Florida Bay. These two sounds are actually part of the Card and Barnes Sound watershed. U.S. Highway 1 forms the western-most boundary of this watershed, and an eastern projection of the Atlantic Coastal Ridge separates it from Biscayne Bay to the north (Hoffmeister, 1974).

Florida Bay. There are three important hydrographic zones in Florida Bay (Turney and Perkins, 1972; Enos and Perkins, 1979; Merriam, 1989).

1) The Eastern Bay, composed of the Upper Bay basin and Crane Key Basin as well as the sounds already discussed. This area is characterized by broad, rounded depressions and considerable freshwater influence;
2) The Central Bay, including Whipray Basin, Calusa Basin, Lignumvitae Basin, and Cotton Key Basin. This area is characterized by small basins, shallow water, and restricted tidal flow; and
3) The Western Bay, characterized by extensive shallow carbonate mud banks, and including Dildo Key Basin, Rabbit Key Basin, Long Key Basin, Sand Key Basin, and Schooner Basin. More tidal exchange occurs here than in the Central or Eastern portions of the Bay.

Natural Features.

Coastal Swamps and Lagoons. Today, freshwater movement into the Lower Everglades generally peaks in October and reaches a minimum during April and May. There is considerable variation in both the quantity and timing of these flows due to variations in annual rainfall. Freshwater sheet flow rates from the Shark River system peak at approximately 0.016 ft/min. (4.9 mm/min.) in the rainy season and fall to zero during the dry season (Parker, 1974).

Under the present, system, the Shark River receives water from the Tamiami Canal control structures and from direct rainfall over the area. Rookery Branch, at the upper end of the Shark River Estuary, exhibits a wide range of both water level and salinity. This seasonal gradient diminishes toward the Gulf and Ponce de Leon Bay. In the lower end of the Shark River estuary system shallow depth, low channel slope, strong tidal flux, and wind combine to produce a well-mixed, homogeneous water column. Tidal velocities approaching 6.4 km/hr (4 knots) have been reported from the lower Shark River (McPherson, 1970).

Taylor Slough is the primary freshwater source for Florida Bay, other than rainfall, and as such it plays a critical roll in many water quality aspects of this study. Taylor Slough receives its freshwater from three sources:

1) Local rainfall;
2) Overland sheet flow originating from the Shark River overflow and Tamiami Canal between levees 30 and 67A.
3) Pump station S-332

Drainage modifications prior to 1960 do not appear to have affected Taylor Slough as drastically as they affected the drainage basins of the western Everglades (Schneider and Waller, 1980). Since that date, however, construction of the C-111 Canal, and increased development in the upland retention areas affecting Taylor Slough, such as the "Frog Pond," have slowly lowered freshwater discharges from that system (Schneider and Waller, 1980).

In 1979 the National Park Service and the U.S. Army Corps of Engineers entered into an agreement stating that an additional 37,000 acre-ft of water per year would be supplied to the upper reaches of the Taylor Slough. Despite the fact this agreement is almost a decade old, conditions in the Taylor Slough area have continued to deteriorate. A 1989 review by U.S. Park Service Personnel of the U.S. Army Corps of Engineers General Design Memorandum for the C-111 Canal stressed the need for more and better timing of freshwater flow into Taylor Slough (Ogden, 1988a).

Whitewater Bay. Whitewater Bay is the largest, and most hydrologically important of the Coastal Lagoons seen in Everglades National Park. It occupies the southern end of the Shark River Slough drainage basin, and has gone through several circulatory and salinity gradient patterns within the recent geological past.

Once primarily a freshwater enclave, submergence over the past 5,000 years has gradually established an oscillating, "double" gradient pattern for salinities within this estuary. In the rainy season the salinity gradient runs along a northeast to southwest axis. In the dry season there is a northwest to southeast salinity gradient representing the effects of tidal flushing at the Bay's mouth. Human modifications in historical drainage patterns have attenuated these oscillations and increased the overall salinity with in this coastal lagoon. Extreme periods of evaporation now regularly produce periods of hypersalinity within the southeastern corner of Whitewater Bay (Tabb, 1967). Tidal and wind packing events control circulation within Whitewater Bay, and to a lesser or greater extent in all the coastal lagoons and lakes seen within the bounds of this study (Schmidt and Davis, 1978).

The Sounds. Geologically two groups or subdivisions of sounds are covered by this study. These are:

1) The Barnes/Card Sound complex, of which Manatee Bay and Barnes Sound are discussed; and

2) The enclosed hydrographic sub-basins of eastern Florida Bay, including Long Sound, Little Blackwater and Blackwater Sounds, Buttonwood and Little Buttonwood Sounds, and Tarpon Basin.

The enclosed sounds of eastern Florida Bay are wind/tide driven systems. Long Sound and Little Blackwater Sounds lie in what is described as the "Runoff Zone" and are periodically influenced by freshwater runoff from the mainland.

Florida Bay. There are three important hydrographic zones in Florida Bay (Ginsburg, 1956):

1) The Eastern Bay, composed of the Upper Bay basin and Crane Key Basin as well as the sounds already discussed. This area is characterized by broad rounded depressions and considerable freshwater influence;
2) The Central Bay, including Whipray Basin, Calusa Basin, Lignumvitae Basin, and Cotton Key Basin. This area is characterized by small basins, shallow water, and restricted tidal flow; and
3) The Western Bay characterized by extensive shallow carbonate mud banks, and including Dildo Key Basin, Rabbit Key Basin; Long Key Basin; Sand Key Basin; and Schooner Basin. More tidal exchange occurs here than in the Central or Eastern portions of the Bay.

These hydrographic zones are roughly analogous to the interior, Atlantic, and Gulf subenvironments discussed by Turney and Perkins (1972). Hydrographic conditions dictate the communities seen in these zones.

Geology and Sediments. The oldest Tertiary rock layers beneath Shark River, Taylor Slough, and Florida Bay are a chalky limestone of marine origin described by Cooke (1945) as Avon Park Limestone. Oscillations of sea level in response to glacial formation and melting have been the primary factors in the formation of post Tertiary rock beneath the Everglades and Florida Bay. Prior to the initial Pleistocene glacial melt, approximately 60,000 years before the present, sea level was nearly 270 ft (83 m) above its present level. At that time, dry land on the Florida peninsula was restricted to a few small islands along the central Florida ridge in what is now Polk County, and one other archipelago in the vicinity of Trail Ridge in Jacksonville. Subsequent glacial melting, accompanied by seafloor expansion, produced sea level fluctuations which gradually left more and more of the Florida Peninsula exposed (Cooke, 1945).

As the sea covering the Florida Plateau retreated, the submerged oolitic ridge, now known as the Atlantic Coastal Ridge, gradually emerged as dry land. Tidal channels were cut through this unstable oolitic ridge, connecting the shallow sea covering what is now the Everglades with the Atlantic Ocean. These channels form the parallel cut and grooves known as the Transverse Glades (Hoffmeister, 1974).

The concurrent fluctuations of sea level and climatic conditions exerted dramatic effects on surface and ground water tables, salt water intrusion, hydroperiod, and consequently on sediment accumulation in the southern Everglades. Major shoreline shifts result primarily from sea level fluctuations, but are augmented by longshore sediment drift, erosion, tidal scouring, and fluctuations in climate and water table (Cottrell, 1989).

Sediments in the Cape Sable area are dominated by infringing and overlapping layers of beach, marl, and peat substrates. To the north of the Northwest Cape and throughout the Shark River Estuary and mouth of Whitewater Bay, the mangrove peat sediments are being actively eroded and swept out to sea by tidal scour (Gebelein, 1977).

Recent sediments in Whitewater Bay show a northeast to southwest grading pattern going from predominantly freshwater peats to predominantly brackish water peats (Cohen and Spackman, 1977). In the mangrove ponds to the northeast, and to a lesser extent within the open water portions of Whitewater Bay, a jello-like, light tan mud called "Liver Mud" is seen, which is believed to result from the mixing of eroded peat with freshwater marl brought in by surface runoff (Schomer and Drew, 1982). Sediments south of Whitewater Bay toward Flamingo and east toward Taylor Slough have an elevated level of marine marl in them. These marine marls are believed to have migrated northward out of Florida Bay and been heaped upon the shoreline by repetitive storm events (Craighead and Gilbert, 1962; Gebelein, 1977).

The sediments of Taylor Slough along the upland boundary of the study area represent a transition zone between upland marsh peats and Florida Bay marls. There are many alternating layers of red mangrove peat and calcitic mud, indicating that neither marine nor freshwater conditions have predominated in this area for long in the recent past. Along the actual coastline where Taylor Slough merges with Florida Bay, there is a defined and continuous layer of red mangrove peat over an older layer of calcitic mud (Cohen, 1989).

The Holocene sedimentary record from Florida Bay shows the asymmetric pattern of transgressive followed by recessive sea level cycles even more clearly than that of the mainland. Prior to the most recent sea level rise, beginning about 4,000 years ago, Florida Bay had developed a terrestrial wetland flora similar to that seen in the Everglades today. As the sea level rose, the encroaching marine waters encountered conditions very similar to those being encountered in the Everglades today. The typical cycle in an upward sea level transgression is 1) freshwater pond, 2) coastal mangrove swamp, 3) shallow bay (lake or basin), 4) mud bank, and eventually 5) island (Enos and Perkins, 1979). The islands seen in Florida Bay today have developed at different times and from different types of sediments, indicating that the mud bank-to-island cycle has persisted throughout most of the Bay's history (Merriam, 1989). Present trends in island formation suggest that eventually Florida Bay will become a coastal carbonate plain with inland mangrove swamps and freshwater ponds similar to the type of habitat seen on the mainland portions of this study area (Enos and Perkins, 1979).

Carbonate mud layers seen in Florida Bay arise primarily from the growth and fragmentation of calcareous green algae such as *Halimeda*, *Udotea*, and *Penicillus* spp. Since these sediments are biogenically produced, water chemistry properties effecting the water/sediment interface are of considerable significance. Salinity, pH, dissolved CO_2 and O_2, and turbidity are important factors in determining the origin, distribution, and accumulation of recent sediments in Florida Bay. Complex interactions among basin configuration, circulation, pollution, animal activity, vegetation, light, temperature, and agitation all play a role in establishing and recording the sediment history of the basins in Florida Bay (Merriam *et al.*, 1989a).

Land Use Patterns. Land use patterns illustrate a predominance of residential activities oriented toward the water and commercial activities along the main (and only) highway. Residential growth and development is occurring at a rapid rate, irrespective of the limitations of a adequate potable water supply, adequate waste disposal alternatives, and impacts on the natural environment. The rapid growth within the Keys is a result of the warm climate and extensive diversity of the natural environment. This growth is having an ever increasing negative impact on the quality of the environment.

Historical Land Use. Just as the climate and diversity of resources attracts people to the Keys today, so it has also in the past. Although the first date of habitation in the Keys is not known, the first native inhabitants were the Tekesta. The Tekesta tribe was divided into smaller bands, of which the Matecumbe were the most important (Goggin and Sommer, 1949).

The natives utilized the rich food resources of the tropical coastal waters, consuming many species of fish, shellfish, and marine reptiles and mammals. Upland animal species such as deer and raccoon, as well as wild plants, probably supplemented their diet. Because there are no deposits of flint or hard stone in the limestone rock of south Florida, many tools were made from the heavier portions of conch shells (Goggin and Sommer, 1949). Archaeological evidence from numerous village sites, middens, and burial mounds, and early observations by Spanish explorers support these findings (Florida Department of Natural Resources, 1985).

In 1902, Henry Flagler began construction of a railroad linking Miami to Key West, which was completed in 1912. This railroad was subsequently destroyed by a hurricane in 1935 and the remaining bridges were used to develop a highway system (Rockland, 1988).

Current Land Use. The Keys are generally divided into three parts: the Upper Keys (Key Largo to Matecumbe), the Middle Keys (Marathon and Islamorada), and the Lower Keys (Big Pine to Key West). For the purposes of this plan uses in the upper and middle keys are considered to border the SWIM planning area.

The Monroe County Planning Department has divided Monroe County (excluding the mainland) into 43 discrete planning units called Planning Areas. The Florida Bay study area includes Planning Areas #28 through #43, which are shown on the Existing Land Use Maps. An overview of land use within the study area will be presented, followed by a description of current land uses as of 1986, by Planning Area. A description of land uses on the mainland will be presented last.

Total existing land uses, by Planning Area, in acres and as a percentage of area for the Keys proper within the study area, are presented in **Table 78.** The land use categories summarized include Residential, Government/Utility (Public), Commercial, and Vacant Land.

As shown in **Table 78,** the predominant land use for the study area (excluding the mainland) is Vacant, which accounts for 75.3 percent of total land uses. The next largest category is residential, comprising 18.7 percent, followed by commercial and government/utility, comprising 4.7 and 1.3 percent, respectively.

Table 78. Existing Land Use Acreages.

		RESIDENTIAL		GOVT/UTIL		COMMERCIAL		VACANT	
PLANNING AREA	Acres	% of Planning Area	Acres	% of Planning Area	Acres	% of Planning Area	Acres	% of Planning Area	TOTAL
28	117.7	10.2	41.7	3.6	10.2	0.9	981.8	85.3	1151.4
29	357.5	41.0	4.4	0.5	50.7	5.8	459.8	53.0	872.4
30	231.9	25.2	25.6	2.8	161.3	17.5	500.3	54.4	919.1
31	28.1	6.9	1.1	0.3	41.8	10.3	333.6	82.4	404.6
32	871.9	51.2	32.2	1.9	43.6	2.6	756.5	44.4	1704.3
33	383.3	23.0	31.9	1.9	61.9	3.7	1193.2	71.4	1670.4
34	315.4	43.6	4.3	0.6	46.1	6.4	356.9	49.4	722.7
35	560.4	38.5	39.4	2.7	95.6	6.6	759.5	52.2	1454.8
36	632.2	38.9	45.8	2.8	52.1	3.2	895.7	55.1	1625.8
37	188.8	22.1	15.8	1.9	17.2	2.0	631.1	74.0	852.9
38	259.7	49.0	0.8	0.2	37.5	7.1	232.1	44.0	530.2
39	4.1	0.9	4.0	0.9	5.8	1.3	426.4	97.0	440.4
40	0.0	0.0	0.0	0.0	0.0	0.0	5910.2	100.0	5910.2
41	50.0	3.0	0.0	0.0	4.0	0.2	1638.3	96.8	1692.4
42	514.2	13.7	63.3	1.7	496.8	13.3	2666.0	71.3	3740.3
43	0.0	0.0	0.0	0.0	15.9	3.3	472.3	96.7	488.2
TOTAL	4515.2	18.7	310.4	1.3	1140.5	4.7	18213.7	75.3	24180.1

Source: Monroe County Planning Department. Florida Keys Comprehensive Plan. Key West, Florida. 1986.

Planning Areas with residential land uses of 40 percent or greater in the area include #29--Lower Matecumbe Key and Craig Key (41.0 percent); #32--Plantation Key (51.2 percent); #34--Key Largo and Dove Creek to Point Charles (43.6 percent); and #38--Key Largo on the northwest side of U.S. Highway 1 from the southwestern edge of Sexton Cove to U.S. Highway 1 (49.0 percent). The Planning Area with the most Government/Utility use is #28--Long Key and Jewfish Key (3.6 percent). Planning Areas with the largest percentage of commercial use include #30--Teatable Key and Upper Matecumbe Key (17.5 percent); and #31--Windley Key (10.3 percent).

Planning Areas with 80 percent or greater vacant land include #28--Long Key and Jewfish Key (85.3 percent); #31--Windley Key (82.4 percent); #39--Port Bougainville and Garden Cove (97.0 percent); #40--Key Largo on the northwest side of State Road 905 from U.S. Highway 1 to the Card Sound Road (100.0 percent); #41--Key Largo from Port Bougainville to the intersection of Card Sound Road and State Road 905 (96.8 percent); and #43--Cross Keys from Jewfish Creek to the Dade County line (96.7 percent).

The predominant land use on the mainland is wetlands, consisting of mangroves and shoreline marsh areas. Much of the mainland area is within the Everglades National Park. There is one small urban complex at Flamingo, on the shore of Florida Bay within the Park. This area contains a marina, motel, restaurant, and visitor center.

Platted lands are found in each of the County's Planning Areas. There are 421 recorded subdivisions, with lot sizes ranging from 5,000 square feet to over an acre. There are an additional 27 unrecorded subdivisions. The subdivisions range in character from fully improved, scarified lands to unimproved native lands. A number of subdivisions are mere "paper" subdivisions, several are subject to tidal inundation on at least a periodic basis, and several are completely submerged. Of the 421 recorded subdivisions, 55 percent have homes developed on fewer than half of the lots, and 33 percent that are not completely built out have homes on fewer than 30 percent of the lots in the subdivision. In a significant number of cases, adjacent lots are owned in common ownership, and many developed homes are located on two lots (Monroe County Planning Department, 1986).

Table 79 presents the estimated number of subdivisions, acreage, and lots by Planning Area. The average lot size in the County for single family residential lots is

Table 79. Summary of Subdivisions - Florida Bay Study Area.

Planning Area	Number of Subdivisions*	Total Acreage**	Total Lots
28	3	102	637
29	14	423	1169
30	15	279	639
31	1	4	6
32	28	899	3607
33	25	496	2294
34	14	271	1459
35	25	824	3628
36	18	734	3402
37	6	258	1267
38	13	322	1629
39	1	98	457
40	2	18	79
41	10	179	726
42	10	471	821
43	1	22	27
TOTAL	186	5400	21847

Source: Monroe County Planning Department, Florida Keys Comprehensive Plan. Key West, Florida, 1986.
* The number of subdivisions may vary by one if any subdivision lies in two Planning Areas.
** These figures are estimates only, subject to verification.

9,800 square feet. This figure represents a weighted average for all subdivisions in the County (Monroe County Planning Department, 1986). Planning Areas #32, 33, and 35 have the greatest number of subdivisions. Those Areas with the greatest acreage in subdivisions include #32, 35, and 36. Planning Areas with the most lots are #32, 33, 35, and 36.

Table 80 presents subdivision lots by land use types. The categories used were native, disturbed, residential, and other. Planning Areas #32 and 38 contain the greatest number of lots in wetland habitat. Areas #35 and 39 contain the most upland habitat lots, whereas #35 has the most disturbed lots. Areas #32 and 35 contain the most residential lots.

2. Hydrologic Features.

Historical Background. Within Florida Bay (**Figure 71**), paramount environmental parameters are the quantity, quality, distribution, and timing of freshwater runoff from the Florida mainland. The flow of freshwater into this system defines and controls the unique natural resources seen there.

Physical drainage patterns in the two major drainage systems, actually delivering freshwater through the Everglades National Park to most of the study area, remain . These drainage routes are as follows:

1) Shark River Slough and associated estuaries on the western side; and
2) Taylor Slough and the C-111 basin on the east.

Table 80. Subdivision Lots by Land Use - Florida Bay Area.

Planning Area	Native Lots*		Disturbed Lots**	Residential Lots***	Other Lots****
	Wetland	Upland			
28	0	0	15	200	422
29	0	26	80	989	74
30	0	12	44	372	211
31	0	0	2	2	2
32	215	19	262	2773	338
33	155	139	141	937	922
34	80	232	10	478	659
35	74	354	544	2301	355
36	69	232	126	1523	1452
37	121	240	45	666	195
38	192	0	160	584	693
39	49	329	27	9	43
40	0	79	0	0	0
41	87	194	230	215	0
42	19	17	75	710	0
TOTAL	1061	1873	1761	11759	5393

Source: Monroe County Planning Department, Florida Keys Comprehensive Plan, Vol. 1. Key West, Florida, 1986.

* Native lots are those which are categorized on the Existing Conditions Map as hammock, pinelands, wetlands and transition zones.

** Disturbed lots are those lots which are categorized on the Existing Conditions Map as scarified and disturbed.

*** Residential lots are those lots which are categorized on the Existing Conditions Map as single-family low, medium and high.

**** "Other" lots are those lots categorized on the Existing Conditions Map as Residential, Commercial, Public, or Utility.

Drainage pattern modifications and extensive development activities in lower Dade and upper Monroe counties have substantially altered both terrestrial and marine communities (Tabb, 1967; Hoffmeister, 1974; Schmidt and Davis, 1978).

Current Conditions.

Shark River Slough and Associated Estuaries. Water movement within Shark River Slough generally peaks in October, with minimum flows occurring during April and May (Leach *et al.* 1972). There is considerable variation in this pattern from year to year, however, based on annual rainfall amounts. Once inside the Everglades National Park, sheet flow predominates in the Shark River system. Surface water flow during periods of high water may reach 1,400 to 1,600 ft/day (427 to 428 m/day). During drought periods, surface water flow rates drop to zero as the water table falls below ground level (Leach *et al.*, 1972).

The estuary zone of Shark River Slough runs from the north end of the study area south to Ponce de Leon Bay. North of Shark River estuary in Ponce de Leon Bay, drainage to the Gulf is primarily through the Lostmans and Broad Rivers, which only partially derive their freshwater from Shark River Slough. South of Ponce de Leon Bay, freshwater runoff from the Shark River Slough enters Whitewater Bay through a series of divergent small rivers, primarily the Watson, North, and Roberts.

Shark River and its associated estuaries are generally well mixed with a homogeneous water column due to the shallow depth, low channel slope, and constant tidal flux. Rookery Branch, at the upper end of the Shark River estuary, shows the widest seasonal fluctuations in water level and salinity for this area. Salinity fluctuations gradually decrease down the estuary toward Ponce de Leon Bay (McPherson, 1970).

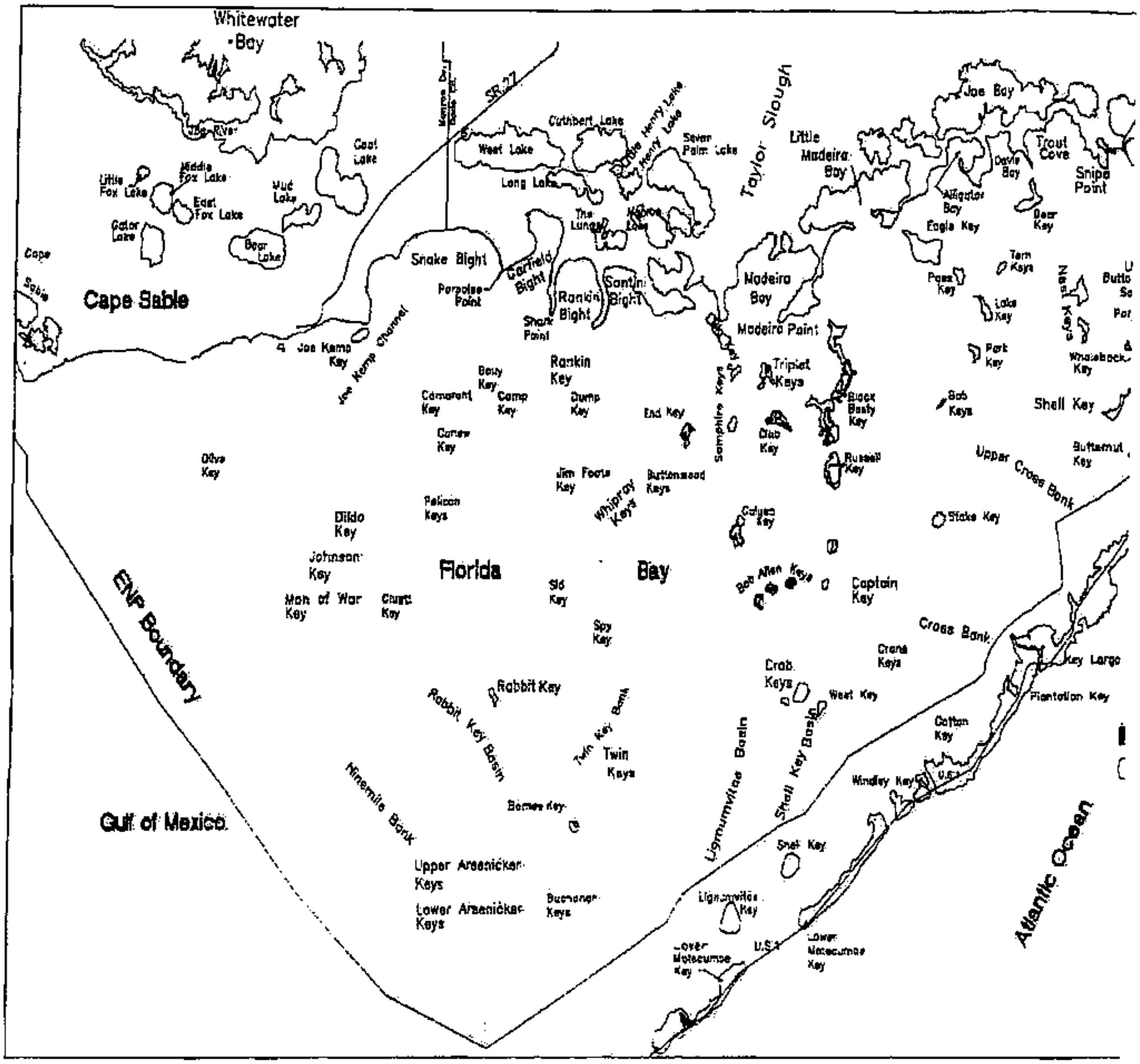
Whitewater Bay. Whitewater Bay is a large and hydrologically important feature at the southern end of the Shark River Slough drainage system. White (1970) suggests, based on the geological evidence, that at lower sea levels, the Shark River Slough flowed directly into what is now Whitewater Bay. As sea level rose, this basin was gradually submerged to form an open water estuary, and historical drainage patterns were modified. Paleo-biological data on mollusks (Lloyd, 1964), and the orientation of the islands within the present day Bay (Ginsburg, 1964), support this conclusion.

Construction of the Buttonwood Canal in 1957 further modified the hydrology of Whitewater Bay, as well as Coot Bay to the south. Prior to the construction of this channel connecting Florida Bay and Whitewater Bay, both Coot Bay and the southern end of Whitewater Bay were essentially wind-driven systems. After construction of the canal, wind packing was almost entirely eliminated from the Coot Bay hydrologic structure and its effects were greatly reduced in south Whitewater Bay. Buttonwood Canal also disrupted the seasonal water supply cycle to the other small lakes south of Coot Bay by allowing direct drainage of this freshwater into Florida Bay (Schomer and Drew, 1982). This canal was closed by the USCOE in 1982 in an effort to restore natural conditions in this area. Although closed in 1982, the connection formed by the Buttonwood Channel between the southern end of Whitewater Bay and Florida Bay allowed some of what was once a totally westward flow toward the Gulf of Mexico, to exit to the south into Florida Bay. It also allowed tidal exchange between the southern end of Whitewater Bay and Florida Bay, increasing salinity fluctuations in that area (Schomer and Drew, 1982).

Rising sea level and increasing tidal influence from the Shark River Estuary to the north had already converted this once freshwater system to a brackish water system before the 1900's (Schomer and Drew, 1982). Subsequent drainage system modifications and reduced freshwater inputs have generated an oscillating double salinity gradient in this water body. In the wet season, a northeast/southwest salinity gradient mimics the historical freshwater influence. In the dry season, a northwest/southeast gradient shows the effects of increased tidal influence and reduced freshwater flow (McPherson, 1970; Clark, 1971).

Florida Bay. Florida Bay is a triangular, tropical lagoon/bay which occupies a shallow, rocky trough between the relic, exposed barrier reefs of the Florida Keys and a series of mangrove-lined bays and sounds at the southern end of the Florida Peninsula (**Figure 72**). Circulation within most of the Bay is primarily tide and wind driven (Schmidt and Davis, 1978), although Gorsline (1963) has reported some slight counterclockwise currents within some of the large basins. Freshwater drainage into Florida Bay is limited to the runoff from Taylor Slough, runoff from the coastal wetlands south of the Shark River Slough system, and groundwater seepage from the mainland. There is an inverse relationship between salinity in northern Florida Bay and the height of the south Florida ground water table (Tabb, 1967; Thomas, 1974).

Restricted flushing in the northern and northeastern basins of Florida Bay causes water levels to vary by as much as 21 in. (53 cm) seasonally (Turney and Perkins, 1972). During normal rainy seasons, Florida Bay exhibits a pronounced gradient of reduced salinity from north to south across the entire bay, whereas in years when rainfall is below normal, the entire Bay may become hypersaline). Despite extreme fluctuations in salinity across the Bay as a whole, three persistent salinity relationships are seen: 1) a northern runoff zone along the mainland, where


Whitewater
Bay
SR 27
Cuthbert Lake
Taylor Slough
Little Madeira Bay
Joe Bay
Trout Cove
Snipe Point
West Lake
Long Lake
Seven Palm Lake
Coot Lake
Mud Lake
Bear Lake
Cape Sable
Snake Bight
Garfield Bight
Rankin Bight
Santini Bight
Porpoise Point
Shark Point
Madeira Bay
Madeira Point
Eagle Key
Bear Key
Joe Kemp Key
Joe Kemp Channel
Rankin Key
Triplet Keys
Shell Key
Olive Key
End Key
Russell Key
Upper Cross Bank
Dildo Key
Johnson Key
Florida
Bay
Captain Key
Man of War Key
Cross Bank
Crab Keys
Key Largo
Plantation Key
Rabbit Key
Rabbit Key Basin
Twin Keys
Lignumvitae Basin
Shell Key Basin
Ninemile Bank
Gulf of Mexico
ENP Boundary
Upper Arsenicker Keys
Lower Arsenicker Keys
Atlantic Ocean

reduced salinities due to freshwater runoff are most frequent and pronounced; 2) a zone of tidal exchange along the southern and western portion of the Bay where salinities are closest to oceanic; and 3) an interior zone where the most severe salinity fluctuations are seen (Merriam *et al.*, 1989a).

Tidal Features. Florida Bay and the western coast of Everglades National Park, covered by this study, are typically described as low energy coastlines. Tidal cycles are diurnal and the range in the outer basins of Florida Bay is normally about 50 cm (20 in). Within the interior of the Bay the tidal range is less, reducing tidal mixing there. Tidal mixing is extremely important in the circulation patterns seen at the southern and southwestern sides of Florida Bay (Tabb *et al.*, 1962; Brown, 1987), and in the Shark River Estuary area on the western side of the Park (McPherson, 1970). Tidal mixing is also extremely important in flushing and mixing within Whitewater Bay, and when the Buttonwood Canal was open, within Coot Bay (Tabb *et al.*, 1962; Clark, 1971). Tidal flushing is least influential along the northern coastline of Florida Bay in the area defined as the runoff zone (Merriam *et al.*, 1989a) or northern subenvironment (Turney and Perkins, 1972). Wind packing, or the forcing of water into and out of Florida Bay by wind and barometric conditions, also plays an important role in Bay and Sound flushing rates (Ginsburg, 1964).

Effects of Hurricanes. Since 1935, two great hurricanes have passed through the study area: Donna in 1960, and Betsy in 1965 (Schomer and Drew, 1982). These two storms had significant but different effects within the study area. Hurricane Donna produced extensive sediments shifts in Florida Bay, depositing as much as 2 in (5 cm) of mud and up to 2 ft (60 cm) of seagrass and benthic debris along coastlines (Perkins and Enos, 1968). Benthic communities were decimated, and extensive destruction was noted in the mangrove fringe areas east of Flamingo (Craighead and Gilbert, 1962; Perkins and Enos, 1968). Hurricane Betsy in 1965 affected essentially a depauperate fauna not yet fully recovered from the effects of Donna. In Hurricane Betsy, sediment shifts were not as pronounced in Florida Bay as they had been during Hurricane Donna. On the west side of Cape Sable ,there was extensive erosion north of the Northwest Cape. It was at this time that the erosion currently affecting the area around the mouth of Big Sable creek first began (Craighead and Gilbert, 1962; Perkins and Enos, 1968).

The storm surge associated with hurricanes is caused by a complex interaction of wind, barometric pressure, and the slope of the bottom topography in adjacent waters. Recorded storm surges in Florida waters have ranged from 9 to 18 ft (2.9 to 5.5 m) above mean normal high tide levels (Simpson *et al.*, 1969). Storm surges in this range would virtually inundate the entire area covered by this study, and the accompanying wind and wave action could be expected to do extensive environmental damage to all habitats seen here.

3. Water Quality.

Water Quality within the Hydrographic Subbasins.

Long Sound, Little Blackwater Sound, and Blackwater Sound. Long Sound lies parallel to the mainland and just west of the U.S. Highway 1 road bed. Originally this sound was heavily influenced by freshwater runoff from the areas south of Homestead. Agricultural and urban development within those areas and the construction of the C-111 Canal, has virtually eliminated that water source today. Long Sound still receives some upland runoff from the lands west of the U.S.

Highway 1 road bed within the Everglades National Park. There is no development and limited access to Long Sound and physically water quality is considered fair. There are periods of hypersalinity and excessively high temperatures in the summers (Tabb, 1967) and occasionally oxygen depletion may occur. The Sound is naturally restricted and poorly flushed.

One boat ramp on the western side of U.S. Highway 1 provides access to Little Blackwater Sound and the upper sections of Florida Bay. As in Long Sound, freshwater intrusions once played a much more important role in the ecology and water quality of Little Blackwater Sound than they do today. Sediments within Little Blackwater Sound are a chalky marl, easily stirred up by wind and wave action and periods of intense turbidity are common. Overall water quality in this sound is again considered fair. Many of the same problems seen in Long Sound are present here. In addition, Little Blackwater Sound is probably receiving some trace metal and hydrocarbon contamination due to its proximity to the U.S. Highway 1 road bed and the increased boating activity seen there.

Blackwater Sound is the largest sound in upper Florida Bay and abuts mid Key Largo. There are four major flushing points allowing water into and out of Blackwater Sound. These are: 1) Jew Fish Creek opening into Barnes Sound; 2) The Boggies, opening on the north side into Upper Florida Bay; 3) Dusenbury Creek, on the southwest corner opening into Tarpon Basin; and 4) The Largo Cut, a man-made access channel cut through the Key Largo limestone on the south side of Blackwater Sound which gives access to Largo Sound and the Atlantic side of the Keys. Both Jew Fish and Dusenbury Creek have been dredged and deepened as part of the Intracoastal Waterway. These cuts and channels have considerably increased the effects of tidal flushing in this sound.

A number of marinas front on the south side of Blackwater Sound and along Jew Fish creek. In addition there has been considerable residential and commercial development along this portion of Key Largo. Currently, water quality within Blackwater Sound is considered good, although the system is receiving gradual nutrient enrichment from Key Largo residential development (Lapointe and O'Connell, 1988) and some hydrocarbon and trace metal contaminates from the extensive boating traffic and marinas seen there. The area has also been reported to feel the effects or freshwater discharges from the C-111 Canal, and reportedly agricultural pesticides linked to these discharges have been detected as far south as the Key Largo Cut and Largo Sound (Skinner, 1988).

Buttonwood and Little Buttonwood Sounds, and Tarpon Basin. Buttonwood Sound, Little Buttonwood Sound, and Tarpon Basin all lie in what is described as the interior subenvironment of Florida Bay. Flushing is negligible and salinities fluctuate widely. Aside from salinity fluctuations and reduced flushing, general water quality conditions in these three sounds are considered fair to good. Some nutrient enrichment, and trace metal and hydrocarbon contamination is probably occurring in Buttonwood Sound and Tarpon Basin from the marinas and developed areas of Key Largo, but the extent of this problem remains unknown at this time.

Upper Bay. The term Upper Bay designates the northeast corner of Florida Bay. The Upper Bay also lies in the interior subenvironment and together with Long and Little Blackwater Sound, this area is most effected by the reduction in freshwater runoff resulting from construction of the C-111 Channel and subsequent lowering of the water table. Salinities here fluctuate from 22 to 52 ppt at varying seasons throughout the year and summer water temperatures may be as high as 38 degrees C (100 degrees F). Although human pollution is slight, this area is definitely a stressed environment (Tabb *et al.*, 1962; T.W. Schmidt and M.B. Robblee, 1989, personal communication, Everglades National Park).

Middle Bay. Middle Bay includes Crane Key Basin, Calusa Basin, Whipray Basin, Dildo Key Basin, and Rabbit Key Basin. These basins again lie in interior subenvironment. They are the basins that have been most effected by the reduction of terrestrial freshwater flow coming through the Taylor Slough drainage system. In these basins there have been fish kills attributed to hypersalinity (T.W. Schmidt, 1989, personal communication, Everglades National Park) and there currently exist a condition in which established seagrass beds are dying out for as yet undetermined reasons (M.B. Robblee, 1989, personal communication, Everglades National Park). This environment is again considered a stressed environment although human pollution sources are very few. Deteriorated water quality and environmental stress in both the Middle and Upper Bay areas of Florida Bay can be directly attributed to the reduced quantity rather than reduced quality of freshwater entering the system.

Atlantic Basins. The Atlantic Basins, or Atlantic subenvironment of Florida Bay is composed of Cotton Key Basin, Lignumvitae Basin, and Long Key Basin. Here there is considerable tidal exchange between the basin waters and those of the Atlantic side of the Keys. Salinities in these areas approach oceanic normal (35 to 41 ppt) and summer water temperatures do not reach the extremes seen in the Middle or Upper Bay. Increased flushing dramatically improves the water quality seen in these areas. At present, water quality is considered good throughout the Atlantic Basins, but there are indications of potential problems in the future. Sewage disposal practices along the Florida Keys, as well as the ever-increasing residential and commercial development taking place there are all contributing or potentially contributing to the deterioration of water quality within the Atlantic subenvironment of Florida Bay (Lapointe and O'Connell, 1988).

Gulf Basins. Schooner Basin and Sandy Key Basin are described as the Gulf Basins because their water quality conditions and biological communities are closely associated with the Gulf of Mexico. Both these basins have high exchange rate with the open Gulf through tidal flux and longshore currents. Water quality within these basins is considered good throughout the year.

Point and Non-Point Pollution Sources and Recommended Containment Strategies. Land use activities as sources of point and non-point pollution to Florida Bay center on three issues: septic tanks associated with residential development, marinas, and inadequate stormwater management. The most commonly used septic tank system in Monroe County is the single tank system. Standards for on-site wastewater treatment facilities have been established for Monroe County by the Department of Health and Rehabilitative Services (HRS), and are implemented by the Monroe County Department of Health, Environmental Health Unit. Little, however, is actually known about the effectiveness of septic tanks in the Keys, or about the long-term implications of septic tank use on Keys' water quality, except that there are no known obvious problems of surface water pollution in conjunction with septic tank usage. Numerous studies of canal systems have been made since 1973, as well as open water discharge areas from wastewater treatment plants. Except for raw sewage discharges, or improperly installed septic tank systems, the surveys showed that the major pollutants were nutrients. Bacteriological tests were seldom in violation of State regulations, except under the previously noted conditions (Monroe County Planning Department, 1986).

The HRS takes the position that properly designed, installed and maintained septic tanks are an appropriate means of wastewater treatment in the Keys (Monroe County Planning Department, 1986). Results from a recent study on the effects of septic tanks on nutrient relations of groundwaters and nearshore surface waters indicated elevated nutrient concentrations in groundwater in the winter and in the nearshore waters in summer (Lapointe and O'Connell, 1988). Determination of water quality impacts requires further study. Of prime importance are the density of septic tanks, age and regular maintenance of the system.

Marinas are of increasing significance as nonpoint sources of surface water pollution. Marina facilities in the study area are listed in **Table 81**. Boat repairs,

Table 81. Marinas in the Florida Bay Study Area.

Map No.	Name	Slips Wet/Dry	Live Aboards	Pump Out Facilities
1	Outdoor Resorts of America	30/01	---	No
2	Bob's Marine South	30/0	---	No
3	Islamorada Yacht Basin	25/0	06	No
4	Topside Resort	17/0	---	No
5	Gamefish Resort	03/0	---	No
6	Lignumvitae Marina	10/0	---	No
7	Rob's Marina	14/0	---	No
8	Lows Marina	30/50	02	No
9	Max Marine	20/50	---	No
10	Max Marine	30/10	01	No
11	Bayside Marine Inc.	40/20	---	No
12	Estes Fishing Camp	01/0	---	No
13	Venetian Shores Marina Inc.	12/0	---	No
14	Plantation Harbor Motel	50/0	---	Yes
15	Plantation Harbor Motel	88/66	50	Yes
16	Tavernier Creek Marina	10/50	---	No
17	Campbell Marina	80/0	06	No
18	Tavernier Surf and Harbor	50/0	15	No
19	Key Largo Ocean Resort	25/0	---	No
20	Rock Harbor	---	---	No
21	Manatee Bay Marina/Boatyard	---	---	---
22	Perdue Marina	30/0	60	No
23	Blue Lagoon MHP and Marina	09/0	---	No
24	King Kampground and Marina	04/0	---	No
25	Twin Harbor	10/50	---	No
26	Deep Six Marina	92/14	01	No
27	Ocean Safari	---	---	No
28	Blackwater Sound	---	---	No
29	Gilberts Motel	25/120	---	No
30	Anchorage Resort	30/0	---	No
31	Cross Key Marina	20/0	01	No
32	Point Laura Marina and Camp	---	11	No

Source: Monroe County Planning Department, Florida Keys Comprehensive Plan

maintenance and fueling require the use of toxic solvents, paints, and petroleum products. In addition, insufficient facilities for disposal of untreated sewage is increasingly becoming a problem due to growth in population and subsequent boat numbers. Currently, only three marinas have sewage pumpout facilities within the study area, as shown in **Table 81**. Little is known of wastewater facilities available to live aboards at these marinas. Finally, inadequate and improperly maintained stormwater management systems are having an impact on surface water quality in Florida Bay. The extent of this problem is not currently known, but an inventory and programs for retrofitting of these systems should be developed.

Inventory of Point and Non-Point Discharge Sources. Nonpoint discharge sources permitted by the DER are listed in **Tables 82 through 89. Table 82** lists two

Table 82. Drainage Wells - Monroe County.

Map No.	Record No.	Facility Name	Facility Type	Design Capacity	Lat/Long
1	5244P00317	Key Largo Shopper	Domestic Waste Injection Well	?	2502.327/8026.33
2	5244P50014	Coastal Waterway	Domestic Waste Injection Well	?	2506.57/8038.02

SOURCE: Florida Department of Environmental Regulation, Drainage Well Permits - Monroe County. Tallahassee, Fl, 1989.

drainage wells within the Keys portion of the study area which are used for the disposal of domestic waste, which includes wastewater derived principally from dwellings, business buildings, institutions and the like; sanitary wastewater and sewage (Rule 17-6, F.A.C.). **Table 83** lists hazardous waste generators within the Keys portion of the study area. These generators are primarily commercial auto sales and service activities, that generate solvents, petroleum products, lead and acids. As indicated in **Table 83**, the Sunoco Service station is inactive. It should be noted that although new wastes are not being generated, this site may still be a source of waste products from previous activities. **Table 85** lists leaking underground storage tanks, of which only one has been located by the DER. This is a leaking fuel tank at the Tavernier Creek Marina (**Table 84**). The tank is near Florida Bay, but the extent and impact of the leaking fuel are not known.

Table 83. Hazardous Waste Generators - Monroe County.

Map No.	Record No.	Facility Name	Facility Type	Design Capacity	Lat/Long
3	5244P80250	J.P. McKenzie Jobber Inc.	Generator	N/A	2502.00/8030.00
4	5013P80731	Largo Honda	Generator	N/A	2505.04/8026.06
5	5244P81170	Sunoco Service Station	Generator (inactive)	N/A	2505.22/8026.35

Source: Florida Department of Environmental Regulation, Hazardous Waste Permits, Monroe County. Tallahassee, Fl, 1989.

Table 84. Leaking Storage Tanks - Monroe County.

Map No.	Record No.	Facility Name	Facility Type	Design Capacity	Lat/Long
6	N/A	Tavernier Creek Marina	leaking underground storage tank	N/A	2500.15/8031.48

Source: Florida Department of Environmental Regulation, Leaking Tank Records, Monroe County. Tallahassee, Fl, 1989.

Table 85 lists solid waste facilities within the Keys. Incinerators are found on Long Key and Key Largo. Daily quantities received are 70 and 93 tons per day, respectively. Typical quantities received are at Long Key and at Key Largo. The incinerators are nonpoint sources of process water from the facilities, which are treated by drain fields, as well as sources of air pollutant emissions. The only landfill within the Keys portion of the study area is on Key Largo, and includes a trash area (Class II) and a residential and domestic waste (Class I) area. A transfer station is also located at the landfill facility. Design capacity of the landfill is 85 tons per day. Typical waste quantities delivered to the facility total 45 tons per day (Florida Department of Environmental Regulation, Landfill Permit Files, 1989).

Table 85. Solid Waste Disposal Facilities - Monroe County.

Map No.	Record No.	Facility Name	Facility Type	Design Capacity**	Lat/Long
7	5244P06134	Long Key	Incinerator*	70 T/D	2449.19/8049.15
8	5244C06173	Key Largo Trash Landfill	Trash/Yard Trash	18 Y/D	2513.55/8020.00
9	5244C07114	Key Largo Landfill	Landfill	85 T/D	2513.55/8020.01
10	5244C04644	Key Largo Transfer Station	Transfer Station	Unknown	2513.55/8025.00
11	5244P06133	Key Largo Incinerators (3)	Incinerator*	105 T/D	2514.10/8019.33

SOURCE: Florida Department of Environmental Regulation, Landfill Permits, Monroe County. Tallahassee, Fl, 1989.
* Process water from these incinerators are treated by drain field.
** T/D = tons per day; Y/D = cubic yards per day.

Table 86 lists industrial discharges, which includes the Florida Keys Aqueduct Authority and two coin laundries. Industrial discharges are those products which result from industrial processes as defined by the Standard Industrial Classification code and selected by the DER (Rule 17-6, F.A.C.).

Table 86. Industrial Discharges - Monroe County.

Map No.	Record No.	Facility Name	Facility Type	Design Capacity*	Lat/Long
12	5244S02021	Florida Keys Aqueduct Authority	Injection Well	1 MGD	2505.16/8027.02
13	5244P02040	Upper Keys Coin Laundry	Trickling Filter	5.6 TGD	2509.18/8023.16
14	5244P02474	Maytag Coin Laundry	Trickling Filter Discharge to Pond	10 TGD	2514.44/8018.55

Source: Florida Department of Environmental Regulation, Industrial Discharge Permits, Monroe Co., Tallahassee, Fl, 1989.
* MGD = million gallons per day; TGD = thousand gallons per day.

Table 87 lists domestic sewage treatment plants, and/or "package plants", which are permitted by the DER. There are 73 permitted facilities within the Keys portion of the study area. The predominant form of sewage treatment is extended aeration (EA). This process was designed for use in small, low flow package treatment plants, which treat wastes from housing subdivisions, isolated institutions, schools and small communities. The process involves screening of solids and debris, followed by aerobic digestion of excess solids and organics by bacteria. A few facilities use the contact stabilization process, which involves the use of partially treated, or activated sludge to absorb organics from untreated sludge. There are also two facilities that use rotating biological contactor processes. This involves the use of paddles coated with treatment bacteria that alternately contact the effluent and the air for aerobic digestion of the wastewater (Tchobanoglous, 1979).

With a few exceptions, most of these facilities are nonpoint discharge sources, utilizing bore holes or injection wells for disposal of secondarily treated domestic wastewater effluent. Four facilities use soakage pits or drain field, which rely on evaporation and infiltration for disposal of effluent. Two facilities use spray irrigation for effluent disposal. Two facilities are point sources, using surface discharge to dispose of effluent. These facilities are listed as discharging to either Jewfish Creek or the Gulf of Mexico.

The mainland portion of the study area includes only one developed area, Flamingo. Flamingo contains a motel and marina, and National Park Service (NPS) facilities. The NPS operates and maintains a 130,000 gallon per day wastewater treatment facility which serves Flamingo. This facility discharges treated effluent into a percolation pond for evaporation and infiltration. There are a number of septic tanks located in the Everglades National Park to serve the primitive campgrounds (R. Getty, 1989, per. com., Everglades National Park).

Tables 88 and 89 list individual and general surface water management permits issued by the SFWMD within the study area. As the tables indicate, permits were issued for residential and commercial development activities, as well as for highway improvements.

Review of Current Permits and Discharge Activities. Permitted potential and actual point and non-point sources of pollution are listed in **Appendix D**. With a few exceptions, the majority of these facilities are non-point discharge sources, utilizing bore holes or injection wells for disposal of secondarily treated domestic wastewater effluent and industrial wastewater. Four wastewater facilities use soakage pits or drain fields, which rely on evaporation and infiltration for disposal of effluent. Two waste facilities use spray irrigation for effluent disposal.

As with septic tanks, discussed previously, domestic wastewater, and industrial wastewater, little is known about the long-term impacts of current disposal practices on Monroe County water quality. Pollution from domestic

Table 87. Domestic Sewage Treatment Plants - Monroe County.

Map No.	Record No.*	Facility Name	Facility Type**	Design Capacity***	Lat/Long
15	5244P05732	Outdoor Resort of America	EA - soakage pit	60	2448.21/8050.35
16	5244S00128	Long Key State Park #3	EA - drain field	2.6	2448.27/3050.07
17	5244P10619	Long Key Townhouse Condo	EA - injection	7	2449.08/8050.55
18	5244P10696	Blue Water Trailer Vill.	EA - bore hole	45	2500.06/8031.14
19	5244P00204	Chico Comm. Bldg.	EA - injection	2.4	2500.16/8031.20
20	5244P00198	Tavernier Towne Shopping Center	CS - soakage pit	60	2500.17/8031.32
21	5244P00225	McMurray Comm. Bldg. STP	EA - injection	10	2500.30/8031.02
22	5244P04452	Driftwood Travel Trailer Park	EA - bore hole	5	2500.41/8030.50
23	5244P05819	Harbor 92 Condo.	EA - bore hole	10	2500.41/8031.06
24	5244P00001	Anchor Condo.	EA - bore hole	9	2501.01/8030.45
25	5244P00046	Planters Pt. WWTP	EA - injection	75	2501.10/8030.00
26	5244P05678	Sunset Acres	EA - bore hole	15	2501.12/8030.48
27	5244P00133	Sunset Hammock Condo.	EA - injection	20	2502.18/8028.47
28	5244P00006	Paradise Pt. MHP	EA - drainage well	3.2	2502.30/8029.27
29	5244P04431	Key Largo Ocean Resort	CS - injection	70	2502.40/8029.26
30	5244P00079	Petersens Condo.	EA - injection	7	2502.48/8029.11
31	5244P01217	Coral Sands Resort	EA - injection	7.5	2502.51/8029.13
32	5244P05878	Silver Shores MHP	EA - bore hole	83	2503.22/8028.47
33	5244P10476	Buttonwood Bay Condo	CS - bore hole	90	2503.40/8028.36
34	5244P0012	Sheraton Key Largo	EA - injection	80	2503.56/8028.19
35	5244P00301	Curry Cove STP	EA - injection	27	2503.57/8028.49
36	5244P04520	America Outdoors Key Largo Inc.	EA - bore hole	15	2504.04/8028.13
37	5244P00276	Fishing Club	EA - injection	10	2504.15/8025.45
38	5244P00212	Krieter Twnhse #1	? - bore hole	1	2504.26/8026.15
39	5244P00213	Krieter Twnhse #2	? - bore hole	1	2504.26/8026.16
40	5244P00214	Krieter Twnhse #3	? - bore hole	1	2504.27/8026.16
41	5244P00211	Krieter Twnhse	? - bore hole	1	2504.27/8026.25
42	5244P00019	Danny's Place	EA - injection	7.5	2504.30/8027.42
43	5244P05432	Rock Harbor Club	CS - bore hole	35	2504.30/8027.50
44	5244P06181	Kawama Yacht Club	EA - injection	80	2504.45/8026.35
45	5244P00237	Hidden Bay Condo	EA - injection	20	2504.50/8026.46
46	5244P00649	The Landings (not in operation)	EA - bore hole	100	2504.50/8027.27
47	5244P00060	Atlantis Key Largo	EA - injection	5	2504.57/8026.16
48	5244P00201	Key Largo Bay Village	EA - bore hole	5	2505.06/8027.06
49	5244P00078	Dolphins Plus	secondary-injection	1.5	2505.12/8026.30
50	6244P00156	Seaside Plaza	? - injection	?	2505.12/8026.56
51	5244P00305	Pilot House Restaurant	EA - injection	15	2505.15/8026.28
52	5244P00145	Pizza Hut-Key Largo	EA - injection	10	2505.20/8026.30
53	5244P04419	Waldorf Plaza Shopping Ctr	EA - injection	30	2505.38/8026.15
54	5244P04261	Holiday Inn Key Largo	EA - bore hole	30	2505.39/8026.16
55	5244P00240	Florida Bay	EA - injection	35	2505.40/8026.35
56	5244P00471	Marina Del Mar	EA - injection; spray irrigation	15	2505.42/8024.15
57	5244P00040	Ocean Divers Rest.	EA - injection	7.5	2505.42/8026.05
58	5244P10796	Holiday by the Sea Condo	EA - bore hole	5	2505.43/8026.14
59	5244P00073	Tradewinds/K-Mart Shopping Ctr.	EA - injection	20	2505.44/8025.04
60	5244P00210	Port Largo Inn	RBC - bore hole	8	2505.46/8025.59
61	5244P00129	Calusa Camp Resort	EA - bore hole	60	2506.36/8025.50
62	5244P00015	Key Largo Kampground & Resort	EA - injection	30	2506.46/8024.58
63	5244P03331	Glens Trailer Park and Campgrounds	EA - bore hole	22	2506.51/8025.24
64	5244P04934	Coastal Waterway Park	EA - bore hole	5	2506.56/8025.25
65	5244P00089	Paradise Pub STP	EA - injection	3.6	2507.12/8024.58
66	5244P00218	Quays Key Largo	EA - injection	12	2507.14/8025.05
67	5244P00236	Torresol Condo	EA - injection	15	2507.20/8025.00

Table 87. Domestic sewage treatment plants - Monroe County. (Continued)

Map No.	Record No.*	Facility Name	Facility Type**	Design Capacity***	Lat/Long
68	5244S03381	John Pennekamp Coral Reef St. Pk.	EA - injection	45	2507.2878024.15
69	5244P00296	The Sanctuary	EA - injection	10	2507.30/8023.40
70	5244P01286	Leeside Prof. Bldg	EA - bore hole	3.3	2507.35/8024.40
71	5244P01031	Hwd. Johnson Motor Lodge - Key Largo	EA - bore hole; spray irrigation	35	2507.48/8024.58
72	5244P00209	The Center of Key Largo	EA - injection	20	2508.13/8024.12
73	5244P00277	Florida Bay Club	RBC - injection	3.6	2508.15/8024.12
74	5244P00056	Sr. Frijoles Rest.	EA - injection	4.6	2508.21/8023.42
75	5244P00036	Italian Fisherman Restaurant	EA - injection	15	2508.30/8024.00
76	5244P01203	Moonbay Condo	EA - bore hole	26	2508.54/8023.37
77	5244P00202	Tamarind Bay Club	EA - bore hole	15	2509.05/8023.32
78	5244P00140	Tamarind Cove Apts	EA - bore hole	15	2509.08/8023.30
79	5244P00939	Tamarind Cove Apts	EA - injection	?	2509.08/8023.30
80	5244P00216	Winn Dixie of Key Largo	EA - injection	5	2509.30/8023.06
81	5244P00147	Key Largo L.T.D. (not built)	STP - injection	2.5	2510.00/8022.55
82	5244C00274	Key Largo Elementary Sch.	EA - bore hole	15	2510.00/8023.00
83	5244P00016	Happy Vagabond Campground	EA - bore hole	15	2510.04/8022.32
83	5244P00290	Gaetano Rest.	EA - injection	5	2510.13/8022.05
84	5244P03112	L'Oasis (point source - surface discharge)	EA - Jewfish Creek	2.6	2510.58/8023.12
85	5244P05489	Gilberts Motel and Marina (point source - surface discharge)	EA - Gulf of Mex.	10	2510.58/8023.23
86	5244P05797	Anchorage Resort and Yacht Club	EA- bore hole	10	2511.10/8023.20
87	5244P00221	Nichols Subdivision	EA - bore hole	10	2512.36/8020.17
88	5244P00474	Cross Key Rest.	EA - drainage	3	2513.00/8026.00

SOURCE: Florida Department of Environmental Regulation, Domestic Sewage Treatment Plant Permits - Monroe County. Tallahassee, Florida, 1989.
* Department of Environmental Regulation Permit Number.
** EA = extended aeration; CS = contact stabilization; RBC = rotating biological contactor.
*** Units in thousand gallons per day.

Table 88. Individual surface water management permits - Florida Bay.

Permit No.	Receiving Body	Use Type	Acreage	Location TWP/RNG
4400053S01	Florida Bay	Residential	13.7	62/39
4400005S	Tidewater	Residential	374.5	60/40
4400040S01	Buttonwood Sound	Residential	24.0	61/39
4400041S01	Tidal	Commercial	25.2	61/39

Source: South Florida Water Management District, Surface Water Management Permits - Monroe County, 1989.

Table 89. General surface water management permits - Florida Bay.

Permit No.	Project	Use Type*	Acreage	Location TWP/RNG
78-71	Long Key Channel	SWM	N/A	unknown
83-5S	U.S. 1 Improvements	HWY	N/A	65/33
83-114S	Bank Facility	SWM	N/A	61/39
83-115S	Tamarind Cove	SWM	N/A	61/39
84-4S	U.S. 1 Widening	HWY	N/A	64/36
84-29S	U.S. 1-Plantation Key	HWY	N/A	63/38
86-120S	Plantation Key Government Center	SWM	N/A	63/38
87-82S	U.S. 1-Plantation Key	HWY	N/A	63/38
88-74S	U.S. 1 Widening at Tavernier Creek	HWY	N/A	62/38

Source: South Florida Water Management District, Surface Water Management Permits - Monroe County, 1989.
* SWM = Surface Water Management; HWY = Highway.

wastewater treatment plants with surface water discharges give the most immediate indication of the extent of water pollution. From 1977 to the early 1980's, several intensive surveys were conducted by the DER at the outfall area of several wastewater treatment plants. None of the sites, including Sigsbee Park Naval

Housing, Key Haven Utility, the Community College, the County Public Service Building, NUAGE Utility, and Key Colony Beach, had degraded the water quality sufficiently to require a mixing zone. The DER has recently initiated a series of monitoring programs; however there are no known water quality problem areas that are attributable to wastewater treatment plant discharges (Monroe County Planning Department, 1986).

Local DER personnel inspect each domestic wastewater treatment plant at least once each year, test the effluent if it appears to be out of limits, and observe and report on maintenance of the system. No violations have been currently recorded (Florida Department of Environmental Regulation, 1989).

Non-permitted Discharge Sources.Information on nonpermitted pollution sources is minimal and incomplete. Conversations with personnel of the DER office in Marathon indicate that seafood processing plants and leaking underground storage tanks are a problem. Effluent from seafood processing plants includes fish parts, offal, and other organic matter which raises biological oxygen demand (BOD) levels in nearshore waters of Florida Bay. Unreported or undetected leaking underground storage tanks are creating groundwater and surface water impacts of unknown extent. Additional monitoring and enforcement is needed (R. J. Hebling, 1989, personal communication, Marathon Field Office, Florida Department of Environmental Regulation).

Areas of Known or Potential Water Quality/Quantity Problems. There are currently three critical areas within the Florida Bay system that have known or potential water quality problems:

1) Central Florida Bay, or the Upper and Middle Bay basins described above;
2) Barnes Sound and Manatee Bay; and
3) The basins and sounds along the shoreline of the Florida Keys.

The lack of sufficient quantities of freshwater delivered to central Florida Bay intensify periods of hypersalinity in that area. Freshwater is delivered to that area through the sloughs east of and including Taylor Slough, through surface sheet flow in high water conditions, and through ground water flow. Tabb (1967) provided evidence that the most significant factor in moderating salinities in Florida Bay is ground water discharges. As he explains, the average rainfall in southern Florida is not enough to cause dilution of the estuaries and is insufficient to prevent an annual deficit between rainfall and evapotranspiration. South Florida is generally classified as having a tropical savannah climate where there is a relatively long and severe dry season, and the rainfall during the wet season is not sufficient to replenish the water lost to evapotranspiration during the dry season. The area is in constant need of water during the dry season, and prior to drainage the balance was maintained by the prolonged and massive displacement of freshwater southward (down gradient) through the Everglades system.

Tabb's study spanned a severe drought and a period of heavier-than-normal rainfall. Results suggested that hypersaline conditions (greater than 50 ppt) resulted in central Florida Bay when ground water elevations in a test well near Homestead fell below 0.55 to 0.61 m (1.8 to 2 ft) mean sea level. Salinity at the Florida Bay stations fluctuated between 25 and 35 ppt when ground water levels fluctuated between 0.61 and 1.7 m (2 and 5.5 ft) mean sea level. Heald (1970) warned that the turtle grass systems could not persist in such hypersalinity events. Seagrass die-off was reported in 1987 (T.W. Schmidt, 1989, personal communication, Everglades

National Park) and has spread since then (M.B. Robblee, 1989, personal communication, Everglades National Park). The Park Service has also noted fish kills (forage fish and juvenile sport fish) possibly resulting from low dissolved oxygen and high hydrogen sulfide conditions (T.W. Schmidt, 1989, personal communication, Everglades National Park). **Table 90** lists the salinity monitoring data base from Florida Bay.

The other area with potential water quality problems is the shoreline adjacent to the Florida Keys. Along the shoreline adjacent to the study area, the potential presently exists for large quantities of nutrient laden water to be injected or released into the ground water. It is estimated that 88 privately maintained package treatment plants release approximately (5.6 x 10^6 m^3/day (1.5 million gallons/day) of treated domestic sewage into shallow wells in this area. This does not include the input from septic tanks of single-family homes and small businesses, which can only be estimated by the existing numbers. The total may approach 7.6 x 10^9 to 11.4 x 10^9 m^3/day (2 to 3 million gallons/day) in the winter. Lapointe and O'Connell (1988) have demonstrated that these outputs are maximized in the winter tourism season. The nutrient-laden ground water is forced into the nearshore areas during the summer rainy season. As recommended by Lapointe and O'Connell, a longer-term (two years or more), more detailed study of this situation needs to be completed to characterize the problem. More data need to be collected to document the degree and extent of eutrophication in the nearshore waters of the Florida Keys.

4. Biotic Systems.

Biological Communities. Florida Bay supports diverse biological communities that are interrelated in a complex ecosystem. The major components of these systems consist of aquatic plant and animal communities and emergent vegetation.

Plankton. The few studies that exist on the plankton of the Florida Bay area can be divided into nearshore phytoplankton and zooplankton studies, ichthyoplankton studies, and studies concerning the planktonic distribution of a specific fishery species. In February and May 1948, Davis and Williams (1950) sampled the plankton of mangrove areas in south Florida from Chokoloskee Bay to Long Sound in northeastern Florida Bay. They found three major influences determining the nature of plankton populations in that area: 1) seasonal influences, 2) the effect of isolation, and 3) the effect of salinity differences. They did not have enough data to clearly show seasonal differences. They did, however, find that isolation is a factor along the north coast of Florida Bay. They found that embayments along this coast could have similar chemical and physical environmental factors but contain different plankton communities. They found that the greatest differences were due to salinity. Desmids and blue-green and green algae were confined to the freshest bodies of water, whereas the abundance of rotifers was inversely proportional to salinity. Finucane and Dragovitch (1959; also reported in Odum *et al.*, 1982) found that dinoflagellates (e.g., *Peridinium* spp. and *Gymnodinium* spp.) may bloom and dominate at times, depending upon the principal water mass influencing the area. In their study of the hydrobiological characteristics of the Shark River Estuary, the U.S Geological Survey (McPherson, 1970) found phytoplankton to be scarce in the estuary but zooplankton and small nektonic animals to be abundant. Greatest concentrations of phytoplankton were found near the mouth (diatoms and other algae) and in the headwaters (filamentous blue-green algae), and increased from a few cells/liter during summer to more than 5,000

Table 90. Historical Salinity Data Base.

Author(s)	Study Title	Years	Type Data	Availability
Davis, J.H.	The ecology and geologic role of mangroves in Florida.	1936-1938	23 stations sampled irregularly	Published 1940
Davis, C.C. and R. H. Williams	Brackish water plankton of mangrove areas in southern Florida	1947-1948	8 stations sampled irregularly	Published 1950
Ginsburg, R.N.	Environmental relationships of grain size and constituent particles in some south Florida carbonate sediments	1953	17 stations sampled irregularly	Published 1956
Finucane, J.H. and A.Dragovich	Counts of red tide organisms, Gymnodinium breve and associated oceanographic data from Florida's west coast, 1954-1957	1955-1957	4 stations sampled monthly	Published 1959
Tabb, D., D.Dubrow, and R. Manning	Hydrographic data from the inshore bays and estuaries of Everglades National Park, Florida 1957-1959	1957-1959	9 stations sampled monthly	Report 1959
Tabb, D. and D. Dubrow	Hydrographic data. Supplement I. From inshore bays and estuaries of Everglades National Park, Florida 1959-1962	1959-1962	7 stations sampled monthly	Report 1962
Lloyd, R. M.	Variations in the oxygen and carbon isotope ratios of Florida Bay mollusks and their environmental significance	1959	10 stations sampled bimonthly	Published 1964
Lyuts, G. W.	Relationships of sediment-size distribution of ecologic factors in Buttonwood Sound, Florida Bay	1962-1963	2 stations sampled irregularly	Published 1966
Tabb,D C., T.R.Alexander, T. M. Thomas, and N. Maynard	The physical, biological, and geological character of the area south of C-111 Canal in extreme southeastern Everglades National Park, Florida	1967	75 stations sampled monthly	Report 1967
Hudson, J. H.,D. M. Allen, and T. J. Costello	Distribution, seasonal abundance, and ecology of juvenile northern pink shrimp, Penaeus duorarum, in the Florida Bay area	1962-1968	22 stations. Some sampled sporadically 1963-1967; sampled monthly 1967-1968	Report 1986
Tabb, D.G., B.Drummond, and N. Kenny	Coastal marshes of southern Florida as habitat for fishes and effects of changes in water supplies on these habitats.	1961-1963	7 stations sampled monthly	Report 1974
Costello, et al.	The flora and fauna of a basin in central Florida Bay	1967	3 stations sampled monthly	Unpublished
Schmidt, T. W.	Study in the area of Black Betsy Key, U.S. 1	1973-1976	14 stations sampled monthly	Unpublished
Creamer, B.	Study in Long Sound area	1977	12 stations sampled irregularly	Unpublished
Patty, et al.	Study in the area of Black Betsy Key, U.S. 1	1977	32 stations sampled irregularly	Unpublished
Ogden, J. C.	Field trip report.	1977	Transect from Tavernier to Taylor River	Unpublished
Evink, G. L.	Hydrological study in the area of Cross Key, Florida	1979-1980	4 stations sampled monthly	Report 1981
Bert, T. M	Stone crab studies	1980-1981	4 stations sampled bimonthly	Report 1986
White, D. and P. Rosendahl	Salinity in northwest Florida Bay	1979-1982	30 to 60 stations sampled biweekly and monthly	Unpublished
South Florida Research Center	Miscellaneous salinity records - monitoring stations	1981-1986	17 stations sampled irregularly	Unpublished
Ratheford, et al.	Larval and juvenile gamefish studies	1982-1984	28 stations some monthly	Unpublished
Shaw, A. B.	Various salinity samplings	1983-1984	Numerous stations	Unpublished
Robblee, M. B.	Various salinity samplings in western Florida Bay (mainly in Johnson Key Basin).	1983-1986	Johnson Key Basin sampled in six-week intervals	Unpublished
Thayer,G.W., W.F.Hettler, A.J.Chester,D.R.Colby, and P. J. McElhaney	Distribution and abundance of fish communities along selected estuarine and marine habitats in Everglades National Park, Florida.	1985-1987	264 stations, several sampled up to three times	Report 1987
Powell,A.B., D.E. Hoss, W.F. Hettler, D.S. Peters, L. Simoneaux, and S. Wagner	Abundance and distribution of ichthyoplankton in Florida Bay	1986-1987	12 stations within Florida Bay sampled irregularly	Report 1987
Powell, G. V. N., W. J. Kenworthy, J. W. Fourqurean	Experiment evidence for nutrient limitations of seagrass growth in a tropical estuary with restricted circulation	1985-1986	5 stations sampled three times	Published 1989
Montague, C. L., R. D. Bartleson, and J. A. Ley	Assessment of benthic communities along salinity gradients in northeast Florida Bay	1986-1987	12 stations sampled bimonthly	Report 1988

cells/liter during winter and spring. The distribution of zooplankton and small nektonic animals could be related to salinity. Copepods (*Acartia tonsa*, *Labidocera aestiva*, *Pseudodiaptomus coronatus*), cumaceans (*Cyclaspis* sp.), chaetognaths (*Sagitta hispida*), bay anchovies (*Anchoa mitchilli*), and scaled sardines (*Harengula pensacolae*) were dominant at the seaward end of the estuary in the highest salinities. Dominant forms in the brackish water of the mid-estuary were amphipods (*Corophium* sp., *Grandidierella* sp.), mysids (*Mysidopsis almyra*, *Gastrosaccus dissimilis*), crab larvae, and young of anchovies, sardines, or related fish. The presence of large numbers of juveniles and young indicated the importance of these brackish waters as nursery grounds.

The National Marine Fisheries Service has conducted ichthyoplankton surveys of the area between Cape Romano and Cape Sable (Lindall *et al.*, 1973; Collins and Finucane, 1984), and within Florida Bay (Powell *et al.*, 1987). Jannke (1971) studied the young *Sciaenidae* in Everglades National Park. Studies by Houde and Chitty (1976), Houde *et al.* (1976, 1979), and Leak (1977) reported information on zooplankton, fish eggs, and fish larvae on the continental shelf adjacent to the study area. Collins and Finucane (1984) sampled the area between Cape Romano and Cape Sable in 1971-1972 and found the area to be a spawning ground and nursery for several recreationally and commercially important fishery species including Gulf flounder (*Paralichthys albigutta*), ladyfish (*Elops saurus*), striped mullet (*Mugil cephalus*), silver perch (*Bairdiella chrysura*), spotted seatrout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellatus*), spanish mackerel (*Scomberomorus maculatus*), sheepshead (*Archosargus probatocephalus*), and pinfish (*Lagodon rhomboides*). They assumed that the occurrence of larvae less than 3.5 mm (1.4 in.) from the 10 most abundant families indicated the location and time that some of these fishes spawned, as well as the direction of larval transport. Some of these small larvae were distributed about equally among the most-seaward, middle, and most-landward stations in the inshore zone (which suggested spawning throughout the less than 32.1 ft [10 m] depths), whereas the smallest larvae of other fishes were caught mainly at the seaward most stations (which suggested spawning in depths greater than 32.1 ft [10 m]). There were great differences in the total number of eggs and larvae and in diversity of larvae between the two zones. Most eggs (95.9%) and larvae (97.9%) were collected in the inshore zone, with all larvae collected at the estuarine stations found in the inshore zone. The variability of salinity in the estuarine zone was probably limiting to numbers of eggs and larvae. When the abundance of eggs and larvae was highest, salinity was moderately high. Roessler (1970) found that all life history stages of fishes showed greater abundances with higher salinities in his studies in the Buttonwood Canal.

Powell, A. B. *et al.* (1987) and Rutherford *et al.* (1986, 1989) focused on the four recreationally important species found within Florida Bay--red drum, snook (*Centropomus undecimalis*), gray snapper (Lutjanus griseus), and spotted seatrout (for a more complete discussion, see Section 2.6.5). Spotted seatrout spawn in intermediate to high salinities of western Florida Bay and adjacent waters, but did not appear to spawn in brackish water habitats in the area or in the Florida Keys. Gray snapper, snook, and red drum spawn outside of Park waters. Juveniles of those species migrate into the Park. Goby larvae dominated larval collections in northwestern Florida Bay and the Shark River area (Powell, A. B. *et al.*, 1987).

McPherson (1970), Lindall *et al.* (1973), and Collins and Finucane (1984) indicate the value of the inshore and estuarine area between Cape Romano and Cape Sable as an important spawning area for many species of fishes. Houde *et al.* (1979) reached similar conclusions for the offshore area. Thus, the entire aquatic region adjacent to the Florida Everglades, including the continental shelf and the western portion of Florida Bay, is of vital importance to the well-being of numerous fish species (Collins and Finucane, 1984).

Benthic Algae. Zieman (1982) states that the primary substrates for benthic macroalgae include 1) sediments, 2) seagrass blades, and 3) rocks or rock outcrops. In addition, many macroalgae in seagrass beds form large unattached masses, collectively known as drift algae. Benthic algae have limited sediment stabilizing properties, the main utility of their rhizoidal holdfasts being to maintain the algae in place. Because they do not have a large investiture of structure in the sediments, the algae can more rapidly accommodate changes in shifting sediments, while still maintaining some current buffering capacity. In this capacity they may form early successional stages for seagrass invasion.

Tabb *et al.* (1962; also reported in Schomer and Drew, 1982) mapped the benthic algae within Whitewater Bay and adjacent Florida Bay in 1960 and 1962. The dominant plant of the salt/fresh transition zone was the macroalga *Chara hornemanni*. Upstream of this zone, the dominant community is freshwater marsh and slough flora of the Everglades. *Batophora oerstedi* was also found in the transition zone on rock outcroppings or wood. *Chara* and *Batophora* preferred low salinities (0-10 ppt) and were observed to achieve greatest areal coverage in winter. Chara has been observed surviving in waters approaching 30 ppt (Schomer and Drew, 1982), and *Batophora* has been reported from hypersaline Florida Bay (Hudson *et al.*, 1970). In his studies in Florida Bay near Key Largo, Morrison (1980, 1984) found that the standing crop of *Batophora* was highest in the summer and lowest in the winter.

In higher salinities in Florida Bay, Tabb *et al.* (1962) found the macroalgae *Acetabularia crenulata, Caulerpa verticillata*, and *Udotea wilsoni* to be dominant species. Invasion of the extensive *Udotea* beds by red algae--*Dasya pedicellata* and *Gracilaria confervoides*--was observed whenever the salinities rose above 20-25 ppt. These algae were found to be epiphytic on *Udotea* or attached to coarser shell gravel. Morrison (1980, 1984), in his studies on *Batophora* near Key Largo, found that the red alga, *Laurencia poitei*, became the dominant species in winter and spring.

Zieman and Fourqurean (1985) measured the distribution and abundance of benthic algae in Florida Bay, Everglades National Park, in 1984. Batophora was the most widely distributed macroalga, occurring at 51% of their stations, but was never the dominant in terms of biomass at any station. *Laurencia* was the most abundant macroalga. Being a drift alga, its distribution is a function of wind and wave energy. The other two major macroalgae, *Acetabularia crenulata* and *Penicillus*, were found sparsely and patchily distributed throughout the Bay. *Penicillus* was found to be especially important where localized conditions prohibit dense seagrass cover. *Acetabularia* and *Batophora* require hard substrate for attachment. Within the study area, the eastward extent of significant stands of the seagrass Syringodium filiforme coincided with the westward extent of *Batophora* distribution. This was explained by the growth requirements of the two plants. The seagrass thrives in the vigorous flushing and soft sediments often found in western Florida Bay, whereas *Batophora* needs a hard substrate more characteristic of the eastern Bay. *Batophora* can survive in a wide variety of environmental conditions, but usually reaches greatest abundance in quiescent waters typical of the eastern Bay.

Montague *et al.* (1989) investigated the benthic algal communities along salinity gradients in northeastern Florida Bay. *Chara* dominated the upstream stations, and *Penicillus* and *Udotea* were the dominant calcareous algae at the outer stations.

Defelice and Lynts (1978, 1979, 1980) studied the marine benthic diatom associations from Long Sound, Little Blackwater Sound, Blackwater Sound, Buttonwood Sound, and northeastern Florida Bay. They found four distinct associations of benthic diatoms. Two associations were epiphytic--occurring on the blades of *Thalassia testudinum*: Association I was characterized by *Cocconeis placentula*, and Association III by *Cylindrotheca closterium* and *Cocconeis placentula*. The other two were epipelic--occurring on the carbonate mud substratum: Association II was characterized by *Cyclotella striata*, *Rhopalodia gibberula*, and *Surirella fastuosa*; Association IV by *Fragilaria crotonensis* and *Cyclotella striata*. The epipelic assemblage was significantly more diverse than the epiphytic assemblage. They noted a general trend of increased diversity away from terrestrial environs towards more open areas of water in both the epipelon and epiphyton.

Geologists have studied the importance of benthic algae in creating sediment. The distribution and abundance of the calcareous algae have not been documented; however, the importance of certain species, e.g., the green algae, *Acetabularia* sp., *Halimeda* sp., *Penicillus* sp., *Rhipocephelus* sp., and *Udotea* sp., and the blue-green algae, *Oscillatoria* sp. and *Schizothrix* sp., in creating sediment in specific habitats has been documented (Ginsburg, 1956; Stockman *et al.*, 1967; Ginsburg *et al.*, 1972; Merriam *et al.*, 1987).

Marine Seagrasses. The bottom of Florida Bay is carpeted with seagrass and macroalgal communities. The dominant macrophyte in the soft bottom communities of Florida Bay is turtle grass, *Thalassia testudinum* (Zieman and Fourqurean, 1985). Other important seagrass species include manatee grass, *Syringodium filiforme*, and shoal grass, *Halodule wrightii*, and at least two species of the genus *Halophila* (*decipiens* and *engelmanni*). Turtle grass is considered to be a climax species in the succession of soft bottom macrophyte communities in south Florida and the Caribbean (Zieman, 1982).

Seagrass beds are highly productive, faunally rich, and ecologically important habitats in south Florida. They serve as nursery areas for juveniles of many commercially and trophically important species, as well as feeding and foraging grounds for numerous adult populations. Seagrass beds are important habitats not only for fish, but also for prey of harvested fish species (Zieman and Fourqurean, 1985).

Tabb *et al.* (1962) described the seagrass communities in Whitewater Bay and adjacent Florida Bay near Cape Sable and Flamingo, between 1957 and 1962. They found Whitewater Bay and Coot Bay to be brackish water, containing a combination of shoal grass and widgeon-grass (*Ruppia maritima*), and that, prior to the opening of the Buttonwood Canal, after a summer of drought in 1957, shoal grass was dominant. The opening of the Buttonwood Canal resulted in the increase of widgeon-grass, and shoal grass almost disappeared. On the marl banks in Florida Bay, they found turtle grass to be the dominant cover. Two general growth forms of turtle grass were described: 1) a stunted and sparse growth of plants 31 to 91 cm (1 to 3 ft) tall in the shallow, highly turbid waters just off Flamingo, and 2) tall, dense stands east of Flamingo and south of Cape Sable in the Sandy Key Basin.

Hudson *et al.* (1970) described the flora of Porpoise Lake, a subbasin within Lignumvitae Basin southeast of Foxtrot Keys and south of Bob Allen Key. They describe the banks as being carpeted with extensive beds of turtle grass which extend into the lake but thin rapidly with increasing water depth. The ridge area between the turtle grass beds and the islands was narrow and covered with sparse patches of shoal grass.

Schmidt (1979) mapped the seagrasses of Florida Bay in Everglades National Park. He divided the Bay into three sections (western bay, central bay, and eastern bay) and identified nine macrophyte communities within the bay, by dominant species. Six community types characterized western Florida Bay: 1) shoal grass-turtle grass; 2) shoal grass-*Gracilaria*; 3) *Caulerpa*; 4) shoal grass; 5) turtle grass; and 6) turtle grass-*Porites*. Four community types characterized central Florida Bay: 1) shoal grass-turtle grass; 2) turtle grass-Batophora; 3) shoal grass-Penicillus; and 4) turtle grass-*Porites*. Four community types characterized eastern Florida Bay: 1) shoal grass-turtle grass; 2) shoal grass-*Penicillus*; 3) turtle grass; and 4) turtle grass-*Porites*. The shoal grass-turtle grass community was the dominant community type, covering over 70% of the study area. In comparing this study with the work by Tabb *et al.* (1962) in northwestern Florida Bay, possible changes in the species composition of western Florida Bay seagrass beds were noted. Turtle grass was gradually being replaced by manatee grass in the Palm and Sandy Key Basins, possibly due to the influence of relatively stable marine salinities and low turbidity found in that area. The changes did not appear to be occurring in Rabbit Key Basin or offshore on the grassy banks southeast of Sandy Key which normally experiences stable marine salinities and low turbidity. Schmidt (1979) attributed the lack of turtle grass in the intermediate area of central Florida Bay to hypersaline conditions as a limiting factor. He noted that the turtle grass beds south of Terrapin Bay appeared stunted and yellow after experiencing several months of hypersaline conditions (60+ ppt.) during the 1974-1975 drought period.

Recent studies by Zieman and Fourqurean (1985) and Thayer *et al.* (1987b) have focused on the distribution and standing crop of seagrasses in Florida Bay. Zieman and Fourqurean (1985) used distributional, standing crop, productivity, and isotope data to define important benthic vegetational communities in Florida Bay. The physical parameters associated with each of the primary benthic communities are summarized in **Table 91**. Each community is described briefly below.

The *Northeast* community was characterized by sparse, patchy turtle grass (0 to 10 g dw/m^2) growing in shallow sediment in the basins. Shoal grass was found throughout this zone and was usually very sparse (less than 1 g dw/m^2). The alga Penicillus was an important macrophyte in this community and the algae Batophora and Acetabularia were found on bedrock outcrops. Banks in this area supported heavily epiphytized, moderate density turtle grass (around 30 g dw/m^2).

The *East-Central* community was dominated by sparse, patchy turtle grass (0 to 20 g dw/m^2) throughout the basins. Deeper sediment was found covering the bottom, eliminating bedrock outcrops for attachment of Batophora. Banks were covered by medium to dense turtle grass with little evidence of epiphytism. The drift alga Laurencia was locally important where concentrated by wind, waves, and current action.

The *Interior* community was defined by dense monospecific stands of turtle grass. Sediments were thick enough to ale Lake, a subbasin within Lignumvitae Basin southeast of Foxtrot Keys and south of Bob Allen Key. They describe the banks

Table 91. Summary of Physical Characteristics of Primary Benthic Vegetation Communities of Florida Bay (From: Zieman and Fourqurean, 1985).

Community and Important Algae	Water Depth (m)	Sediment Depth (cm)	Water Clarity	Salinity and Temperature	Terrestrial Input	Seagrass Species	*Thalassia* Standing Crop (g/m2)
NORTHEAST *Batophora*	1.5	0-5	Bottom stirs up in light wind	Variable	Intermediate	*Thalassia*, *Halodule*	0-30
EAST-CENTRAL *Laurencia*	2.0	3-6	Bottom stirs up in moderate wind	Moderately variable	Low to intermediate	*Thalassia*, *Halodule*	10-60
INTERIOR *Laurencia*	2.5	20-50	Generally clear	Moderately stable	Low	*Thalassia*, *Halodule*	50-60
ATLANTIC *Halimeda*, *Penicillus*	2.5	0-20	Generally clear	Very stable	Lowest	*Thalassia*, *Syringodium*	20-120
GULF *Laurencia*	2.5	10-80	Generally clear	Very stable	Low	*Thalassia*, *Syringodium*	60-125
MAINLAND *Batophora*, *Laurencia*	1.0	Varies	Generally turbid	Highly variable	High	*Thalassia*, *Syringodium* *Halodule*, *Ruppia*	0-100
CONCHIE CHANNEL	1.0-3.0		Very turbid	Variable	High	None	---

as being carpeted with extensive beds of turtle grass which extend into the lake but thin rapidly with increasing water depth. The fringe area between the turtle grass beds and the islands was narrow and covered with sparse patches of shoal grass.

The *Mainland* community was heterogeneous and heavily affected by terrestrial influence. Highly epiphytized turtle grass was the dominant macrophyte in densities similar to the Interior community, but nearly monotypic stands of shoal grass were found, with densities of 90 g dw/m^2 and higher. Widgeon-grass was found along the mangrove fringe of the mainland in the easternmost areas of this community. Manatee grass was found in the deeper waters of the western areas of this community. Water depths were shallow, and turbid conditions common. The alga Batophora was common on hard bottom.

The *Gulf* community was the most diverse, with high density turtle grass beds (75 to 125 g dw/m^2) interspersed with shoal grass and manatee grass. Manatee grass was dominant at greater depths (around 3 m). Localized areas of bedrock outcrops were found with live bottom communities. The drift alga Laurencia was locally important on the banks.

The *Atlantic* community was characterized by sparse turtle grass (20 g dw/m^2) in deep water and lush turtle grass (up to 400 g dw/m^2) on firm banks (mean, 90 g dw/m^2). Dense manatee grass was found in deep bottoms of tidal channels through the banks. Basin floors contain shallow accumulations of coarse sediment. Occasional bedrock outcrops contain live bottom communities. The calcareous algae Halimeda and Penicillus were the dominant macroalgae.

The *Conchie Channel* community corresponds with the area of Florida Bay studied by Tabb *et al.* (1962). Conchie Channel is a deep, highly turbid tidal channel just south of Cape Sable that drains the basins to the south and east of Flamingo. The bottom is hard packed mud or muddy shell sand with infrequent bedrock outcrops with sparse live bottom. Macrophyte cover was generally lacking, with only widely scattered turtle grass and shoal grass (densities approximately 1 g dw/m^2).

Zieman and Fourqurean (1985) described some similarities between their communities and those described by Schmidt (1979). The Northeast community approximates the turtle grass-*Batophora* community; the Atlantic, the turtle grass-*Porites* community; the Gulf, the turtle grass-manatee grass community. The relative areal coverage and position of similar community pairs differed greatly between the two studies. Shoal grass appears to have declined in importance between the two study periods (1973-1976 and 1983-1984). Both the Gulf community and the Atlantic community appear to have encroached into the interior of Florida Bay.

Thayer *et al.* (1987), in their study relating fish populations to habitat, divided Florida Bay into five strata: I, eastern Bay; II, mid-Bay; III, west Bay; IV, channels; and V, Coot Bay and a portion of Whitewater Bay. They found that turtle grass dominated the standing crop biomass of seagrasses in Florida Bay and occurred at almost every sampling site where seagrass was present. Manatee grass and shoal grass contributed substantially to shoot densities in open water areas of Strata III and in the channels (Strata IV). When data for the three species were combined, total standing crop and shoot density were highest in Strata III. Total standing crop averaged 230, 221, 206, and 59 g dw/m^2 for Strata IV, III, II, and I, respectively, with corresponding shoot density averages of 1866, 1719, 1024, and 535 shoots/m^2. Strata I, II, and III correspond, respectively, to the Atlantic, Interior, and Gulf communities of Zieman and Fourqurean (1985). In that study, those communities were characterized as predominantly turtle grass, with densities for that species varying between communities but showing a general trend of increasing from east to west, coinciding with increased sediment depth.

Coot Bay and Whitewater Bay had the lowest overall abundances of seagrasses of areas sampled by Thayer *et al.* (1987). Many stations in Coot Bay were devoid of seagrasses; where seagrasses were present, widgeon grass was prevalent, with a mean standing crop of 5.3 g dw/m^2 and shoot density of 636 shoots/m^2. During the period May 1984-June 1985, the alga Chara expanded its area in Coot Bay. Shoal grass, which was also present, had a mean standing crop of 1.3 g dw/m^2 and a shoot density of 109 shoots/m^2. Shoal grass was predominant in Whitewater Bay, with a mean standing crop of 6.0 g dw/m^2 and a shoot density of 534 shoots/m^2. Widgeon grass was also present, with an average standing crop of 3.4 g dw/m^2 and a shoot density of 366 shoots/m^2. This grass had expanded its area and density in March 1985 in northeast Whitewater Bay, when there was a standing crop of 77 g dw/m^2 and a shoot density of 8,700 shoots/m^2.

Two recent studies have focused on specific areas or habitats in Florida Bay. Montague *et al.* (1989) provides an assessment of benthic habitats along salinity gradients in northeast Florida Bay. G. V. N. Powell *et al.* (1987) studied the ecology of shallow bank habitats in the Bay.

Montague *et al.* (1989) sampled three transects: 1) from the mouth of Little Madeira Bay into the Taylor River; 2) from Trout Cove into Trout Creek and Snook Creek; and 3) from Little Blackwater Sound, into Long Sound and up Highway Creek. Turtle grass dominated the outermost stations in Little Madeira Bay and Trout Cove, with densities varying between 563 and 1400 g dw/m^2 at these locations. The calcareous alga Penicillus was dominant in Little Blackwater Sound, with a small percentage of turtle grass. Shoal grass and turtle grass dominated in near equal amounts at the next stations upstream on each transect. Further upstream in each system, turtle grass became less dominant and shoal grass, widgeon grass, and the alga Chara became more influential. The outermost stations sampled in this study coincide with the Mainland (Little Blackwater Sound and Little Madeira Bay) and Northeast (Trout Cove) communities of Zieman and Fourqurean (1985). Actually, Little Blackwater Sound as described by Montague *et al.* (1989) is more similar to the Northeast community of Zieman and Fourqurean (1985) with sparse, patchy turtle grass and Penicillus. Little Madeira Bay and Trout Cove are similar to the Mainland community, with turtle grass as the dominant macrophyte being replaced with shoal grass and widgeon grass as salinities become reduced.

Powell, G. V. N. *et al.* (1987) studied five bank habitats located in each of the major vegetational divisions of Zieman and Fourqurean (1985). Eagle Bank is located in the Northeast community; Cross Bank, in the East-Central community; Whipray Basin, in the Interior community; Buchanan Bank, in the Atlantic community; and Oyster Bank, in the Gulf community. The mean standing crop values for turtle grass along transects at Eagle Bank, Cross Bank, Whipray Basin (Dumps Bank), and Buchanan Bank were 33.4, 60.0, 73, and 90.0 g dw/m^2, respectively, coinciding closely with the values for the respective communities of Zieman and Fourqurean (1985). Oyster Bank was found to have a much lower mean standing crop than reported by Zieman and Fourqurean (1985). Oyster Bank was found by Powell, G. V. N. *et al.* (1987) to have high turbidity which may have caused the reduced density values at that site. Oyster Bank had the sparsest turtle grass density of any site; however, shoal grass and manatee grass were found in the highest densities of any site at this location. At the Buchanan, Cross, and Eagle sites, a progression of richness in vegetation was noted from one side of the bank to the other. The trend appeared to be related to relative exposure to wind-induced wave action, with seagrass lushness decreasing from protected to the exposed side of banks. This progression was not apparent at the Oyster or Dumps site because these banks were broad, and relatively sheltered from wind effects.

One recently recognized function of seagrass beds is their ability to export large quantities of organic matter from the beds for utilization at some distant location (Zieman *et al.*, 1979; Zieman, 1982). This exported material is both a carbon and nitrogen source for benthic, mid-water, and surface-feeding organisms at considerable distances from the original seagrass beds. The seagrass blades can be detached by herbivores, low tides or wave action, or major storms (which can tear out whole plants).

Live Bottom. Live bottom refers to the communities of attached invertebrate fauna (e.g., corals and sponges) found within some areas of Florida Bay. Live bottom communities are found within Florida Bay where there is hard bottom and good circulation of Gulf of Mexico or Atlantic Ocean waters. From data provided by Thayer *et al.* (1987) (see Section 2.5.2 on surficial sediments), the southeastern portion of the study area would have the greatest potential to contain hard bottom areas.

Schmidt (1979) recognized nine macrobiotic communities in Florida Bay within Everglades National Park; all but one, the *Thalassia-Porites* community, was defined by the major macrophyte components. The *Thalassia-Porites* community is found along the southeastern boundary of the Park along the Florida Keys. Hudson *et al.* (1970), in their study of Porpoise Lake (found within the *Thalassia-Porites* community of Schmidt [1979]), describe the seagrass beds as having a discontinuous distribution of *Porites furcata*. They also noted the knobby star coral, *Solenastrea hyades* on hard bottom in the canals transecting the banks.

Schomer and Drew (1982), adopting the subenvironments of Turney and Perkins (1972), described the Atlantic subenvironment as having abundant *Porites furcata*, common *Siderastrea* and *Alcyonaria*, and few *Solenastrea*; the Interior subenvironment, very rare *Siderastrea* and rare *Porites*, *Solenastrea*, and *Alcyonaria* near margins; the Gulf subenvironment, common Porites furcata and rare *Alcyonaria* and *Solenastrea*. Attached invertebrates were absent in the Northern subenvironment.

Zieman and Fourqurean (1985) found local hard bottom areas in the middle of basins within the Gulf community. These hard bottom areas supported gorgonians, alcyonarians, hardy corals such as Siderastrea, and sponges. The Atlantic community contained occasional bedrock outcrops colonized by dense stands of gorgonians and the hardy hermatypic corals *Porites* and *Siderastrea*.

Fish. Schmidt (1979) summarizes the early fish studies in the Florida Bay area. Henshall (1891) prepared a list of fishes from the Cape Sable region. Tabb and Manning (1962) prepared an annotated checklist of fish and invertebrate fauna from Whitewater Bay and northern Florida Bay, and Roessler (1970) provided an annotated checklist for the Buttonwood Canal. Hudson *et al.* (1970) included a listing of fishes in their inventory of species from Porpoise Lake. The U.S. Geological Survey study of the Shark River estuary (McPherson, 1970) included fish collections, using a combination of trawls, nets and seines. Lindall *et al.* (1973) conducted a survey of fishes and invertebrates along the Gulf of Mexico shoreline between Cape Romano and Cape Sable, using a combination of trawl and seine collections. A study of the Ten Thousand Islands area by the U.S. Environmental Protection Agency (Carter *et al.*, 1973) was the first systematic survey in Florida on the relative abundance of estuarine and marine fishes by number and biomass. Clark (1974) studied the variability of trawl data in Whitewater Bay. Davis and Hilsenbeck (1974) and Schmidt (1989) sampled fish in the Whitewater Bay area, using bottom trawls.

Zieman (1982) and Odum *et al.* (1982) provide a general listing of invertebrate and fish species found in seagrass and mangrove habitats. The structure of the seagrass bed with its calm water and many microhabitats provides living space for a rich epifauna of both mobile and sessile organisms including gastropods, amphipods, isopods, and polychaetes. These organisms are of the greatest importance to higher consumers within the grass beds, especially fishes (Zieman, 1982). Mangroves serve two distinct roles for fishes: 1) the mangrove-water interface, generally the red mangrove prop roots, affords a relatively protected habitat which is particularly suitable for juvenile fishes and an attachment surface for sessile filter feeding invertebrates; and 2) mangrove leaves are the basic energy source of a detritus-based food web on which many fishes are dependent (Odum *et al.*, 1982) (see Sections 2.6.6 and 2.7 for further discussion).

Schmidt (1979) provides a summary of a 40-month study to determine the composition, diversity, distribution, and relative abundance of the fish fauna in Florida Bay. During that study, 182,530 fishes representing 128 species and 50 families (674.9 kg [1,488 lb], total biomass) were collected in seines and trawls at 27 stations in the Bay. An additional 21 species were identified from sport fish surveys. Overall, five species comprised 75% of the numerical total and 11 species made up 75% of the total biomass. In western Florida Bay, species dominating numerically were anchovies, specifically striped anchovy, *Anchoa hepsetus* and bay anchovy *Anchoa mitchilli*; in the central portion of the Bay, silver jenny, *Eucinostomus gula* and pinfish, *Lagodon rhomboides*; and in eastern Florida Bay, the hardhead silversides, *Antherinomorus stipes* and gold-spotted killifish, *Floridichthys carpio*.

The silver jenny was the biomass dominant throughout the Bay system. Excluding the silver jenny, the most abundant species by weight in western Florida Bay were pinfish, southern stingray, *Dasyatis americana*, and silver perch, *Bairdiella chrysura*; in central Florida Bay, the pinfish, gray snapper, *Lutjanus griseus*, and scrawled cowfish, *Lactophrys quadricornis;* and in eastern Florida Bay, the hardhead silversides and hardhead halfbeak, *Chriodorus atherinoides*.

The study by Schmidt (1979) also showed that the distribution and abundances of fishes varied according to hydroperiod, region, habitat, and salinity. The greatest numbers and biomass of fishes occurred during the wet season (summer and fall months) whereas the lowest numbers and biomass appeared during the dry season (winter and spring months). Fish abundance and diversity were highest in western Florida Bay, followed by the eastern and central regions, respectively. Certain species and age-sizes of fish were abundant only in particular macrobiotic communities and habitats. The 0 age group pinfish, silver perch, and grunts seasonally dominated the shallow seagrass flats whereas older (age I) fish were commonly found only in the seagrass-covered basin areas. The anchovies dominated the shallow rock and shell channels and the sparsely vegetated intertidal mud-flats of moderate salinities in western Florida Bay. The hardhead silversides and halfbeaks dominated the hypersaline, open water catches over stunted seagrass beds in eastern Florida Bay. Salinity was the major environmental limiting factor affecting fish distribution, particularly in north central and northeastern Florida Bay.

Thayer *et al.* (1987) studied the distribution and abundance of fish in seagrass and mangrove habitats in the Park. In the seagrass habitat, they collected 43,578 individuals of 93 species in nine surveys between May 1984 and June 1985, using surface and otter trawls. Twelve species contributed 91.0% of the total number of fish collected by otter trawl: rainwater killifish (*Lucania parva)*; silver jenny; pinfish; bay anchovy; gold-spotted killifish; white grunt (*Haemulon plumieri*); dusky pipefish (*Syngnathus floridae*); silver perch (*Bairdiella chrysoura*); pigfish (*Orthopristis chrysoptera*); gulf pipefish (*Syngnathus scovelli*); hardhead silverside; and gulf toadfish (*Opsanus beta*). Bay anchovy dominated the surface trawl catches, followed by halfbeak (*Hyporhamphus unifasciatus*); reef silverside (*Hypoatherina harringtonensis*); rough silverside (*Membras martinica*); hardhead silverside; redfin needlefish (*Strongylura notata*); hardheaded halfbeak; striped anchovy; silver jenny; rainwater killifish; and Spanish sardine (*Sardinella aurita*). Twelve species dominated the biomass of fishes collected by otter trawls: pinfish; silver jenny; hardhead catfish (*Arius felis*); pigfish; white grunt; gulf toadfish; silver perch; gray snapper; gafftopsail catfish (*Bagre marinus*); scrawled cowfish; inshore lizardfish (*Synodus foetens*); and bluestriped grunt (*Haemulon sciurus*). Nine species dominated the biomass collected by surface gear: halfbeak; redfin needlefish; hardhead halfbeak; ballyhoo (*Hemiramphus brasiliensis*); timucu (*Strongylura timucu*); bay anchovy; rough silverside; pinfish; and silver jenny.

In the study by Thayer *et al.* (1987), the seagrass sampling stations were divided into five strata (see Section 2.6.3 for explanation of strata). Analysis showed that, although many demersal and pelagic fish species co-occurred in the three open water strata (I, II, III, and IV), western Florida Bay (Strata III) contained the greatest number of species collected solely in that strata. In general, few species were unique to any one strata. Salinity was the limiting factor to co-occurrence of species in Whitewater Bay and Coot Bay (Strata V) and the open water strata.

Within mangrove habitats in Florida Bay, a total of 14,482 fish distributed among 87 species were collected during the study period (Thayer *et al.*, 1987). The ten dominant species were hardhead silverside; silver jenny; bay anchovy; gold-spotted killifish; rainwater killifish; spotfin mojarra (*Eucinostomus argenteus*); code goby (*Gobiosoma robustum*); striped anchovy; gulf pipefish; and clown goby (*Microgobius gulosus*). Silver jenny, bay anchovy, and gulf pipefish were more abundant in adjacent seagrass beds than in the mangrove sites. Based on a few day-night comparisons, the trend appears to be towards higher abundances of fishes among the mangrove prop roots during daylight, and greater diversity at night. The mangrove habitat exhibits an overall greater density and standing crop biomass of fishes than the adjacent fringing seagrass habitat. Overall the two habitats support different fish communities during daylight and night hours, and fulfill different functions for different species of fish.

In their study of bank habitats in Florida Bay, Powell, G. V. N. *et al.* (1987) divided the community into demersal (epibenthic) and pelagic species. Fifty-six species of demersal fish were caught. The dominant species in total abundance were gold spotted killifish, rainwater killifish, gulf toadfish, code goby, and fringed pipefish (*Anarchopterus criniger*). Seventy-one species of pelagic fish were caught, with the dominant being (not in order of importance) silver jenny; sea catfish; fantail mullet (*Mugil trichodon*); striped mullet (*Mugil cephalus*), silver mullet (*Mugil curema*); Atlantic thread herring (*Opisthonema oglinum*); scaled sardine (*Harengula jaguana*); pinfish; silver perch; redfin needlefish; gray snapper; ladyfish (*Elops saurus*); spotted seatrout (*Cynoscion nebulosus*); bluestriped grunt; crevalle jack (*Caranx hippos*); pigfish; and halfbeak.

Schmidt (1986, 1989) has studied the food habits of juvenile lemon sharks (*Negaprion brevirostris*) and young great barracuda (*Sphyraena barracuda*) in Florida Bay. Juvenile lemon sharks were found to feed on small demersal fish, predominantly gulf toadfish and pinfish. Young barracuda feed on small epibenthic fish, mainly gold-spotted killifish and rainwater killifish.

Tilmant (1989) summarizes the history of commercial and recreational fisheries in Florida Bay. Florida Bay was added to Everglades National Park in 1950, and in 1951 government regulations were established to control fishery harvest. Commercial trawling for shrimp and trapping for lobster was prohibited in the Park; however, commercial fishing for mullet, spotted seatrout, and other finfish, as well as trapping of stone crabs, was allowed to continue in specific areas and using designated gear. Information on the dynamics of the sport and commercial fisheries in the Park began in 1958 with a series of reports issued by the Institute of Marine Science of the University of Miami to the National Park Service (Rosen and Dobkin, 1958; Higman and Steward, 1961; Higman and Yokel, 1962a,b; Higman and Roessler, 1963; Rouse and Higman, 1964; and Dooley and Higman, 1965). These studies were the foundation of an expanded monitoring program instituted by the National Park Service in 1972. The program provided detailed data on the fishing effort and harvest of commercial and recreational fisheries and documented growth in commercial fishing activities and declines in stock of popular sport fish during the 1970's. The National Park Service placed restrictions on sport fishing in 1980 and announced a phase-out of all commercial fishing in Florida Bay by 1985 (U.S. Department of the Interior, National Park Service, 1979). Particularly important sport fish species are snook (*Centropomus undecimalis*), gray snapper, spotted seatrout, and red drum (*Sciaenops ocellatus*).

Studies on snook in Florida Bay were begun by Marshall (1958) and Volpe (1959). More recent studies have studied the age, growth, and mortality (Thue *et al.*, 1982); early life history (Rutherford *et al.*, 1986, 1989); and fishery harvest and population dynamics (Tilmant *et al.*, 1989). Thue *et al.* (1982) used scale annuli to age snook, finding that snook in the Park were mainly four- and five-year olds. Recruitment into the fishery began at age two and was completed by age six. Mean calculated growth was 375 mm (14.8 in.) in the first year, and 57-90 mm (2.2-3.5 in.) thereafter. Fish taken from Whitewater Bay-Coot Bay were larger at ages one through four than fish of the same age from the north Florida Bay-Cape Sable area. Rutherford *et al.* (1989) found that snook apparently do not inhabit Florida Bay as larvae or juveniles. Juveniles 269-423 mm (10.6-16.6 in.) (1-2 years old) were collected in Whitewater Bay. Since 1974, the average length of snook harvested in the Park has been approximately 635 mm (25.0 in.) (age 4.5 years). A minimum size of 610 mm (34 in.) was placed on the fishery in 1985; 31% of the fish harvested have been less than the minimum length. Average size of the population increased to 711 mm (30.0 in.) in 1975 and 1982, possibly reflecting low recruitment year classes. An apparent increase in recruitment occurred in 1983 and 1984 following high rainfall years of 1982 and 1983. This suggests that larval recruitment and/or juvenile survival may be enhanced by increased upland runoff or marsh flooding. Management techniques (bag limits, minimum size limits, and closed seasons) have not resulted in reduced annual harvests (Tilmant *et al.*, 1989).

Gray snapper enter the Park waters as postlarvae and small juveniles, inhabiting seagrass beds in banks, basins and channels, and mangrove prop roots. Juvenile gray snapper were most abundant in mixed seagrass beds of Florida Bay (Rutherford *et al.*, 1986, 1989). Fish aged using scale annuli ranged from 1-7 years (mean age, 3 years). Growth is greatest in the first year and relatively linear before increasing in the fifth year. Spawning activity probably occurs outside of the Park waters. The gray snapper diet consist mainly of fish, shrimp, and crabs (Rutherford *et al.*, 1983). Total annual harvest of gray snapper in Florida Bay and adjacent waters has dropped from 129,000 to 99,500 in 1973-1976, increased greatly to 156,000 fish in the mid-1970's, but declined again during the 1980's to 59,000 fish. The increase in the 1970's was due to an increase in guide harvest. The decline in effort, harvest, and harvest rates in the 1980's is believed due to increase in effort for other species such as seatrout, as well as reduced stock abundance and recruitment (Rutherford *et al.*, 1987).

Spotted seatrout was the only sport fish found to spawn in Park waters, predominantly western Florida Bay (Powell, A. B. *et al.* 1987). Spotted seatrout larvae were found in every month but January, with peaks in June to September. Juveniles were collected in mixed seagrass beds and were most abundant in western Florida Bay (Rutherford *et al.*, 1986). Age of harvested seatrout ranged from 1 to 7 years. Estimated population in the Flamingo area ranged from 686,000 to 786,000 fish from 1974-1978, and then decreased slowly to 631,800 by 1984. Recruitment varied during that period but was lowest in 1983. Recruitment appears loosely correlated with rainfall and water levels in upland marshes (Rutherford *et al.*, 1989). The seatrout harvest has changed through the years with changes in the fishery (commercial and recreational); however, since 1980 when bag limits of 10 fish per person were initiated, total annual harvest has increased to early 1970 levels, with increases in both recreational and guided harvest. Current harvest levels have moderate impact on the stock (Rutherford *et al.*, 1989).

Red drum spawn outside of Park waters but larvae enter the Park from September to January and inhabit shallow brackish waters near mangrove shorelines and in creeks. Larval catches have decreased in the last 20 years (Rutherford *et al.*, 1986, 1989). The red drum fishery consists largely of newly recruited fish, as maturing fish are known to migrate offshore. Increased recruitment to the fishery has been observed to follow high rainfall years, suggesting improved recruitment and/or survival of early stage juveniles during periods of increased upland runoff (Tilmant *et al.*, 1989). The popularity of red drum increased from a species specifically sought by less than 7% of the fishermen in the late 1950's to one sought by over 40% of the fishermen in Florida Bay during 1986. This resulted in an increasing percentage of the available stock being harvested. A 457.2 mm (18 in.) size limit placed on the fishery in August 1985 and a closed season in November 1986, both have contributed to some decrease in the total annual reported catch. However, a decline in the reported catch rate and a radical increase in the mean size harvested (well beyond the limit) suggest a decline in population and recruitment or an increase in mortality in recent years (Tilmant *et al.*, 1989).

Florida Bay has had, or is linked to, commercial fisheries for pink shrimp (*Penaeus duorarum*), spiny lobster (*Panulirus argus*), and stone crab (*Menippe mercenaria*). The Tortugas fishery for pink shrimp was discovered and studied by the Institute of Marine Science of the University of Miami. Dobkin (1961) and Ewald (1965) described the early life stages of pink shrimp from tank rearing and plankton samples. Jones *et al.* (1970) described the distribution of early developmental stages, finding that the species entered Florida Bay as postlarvae and moved to inshore waters as the postlarvae became older. Beardsley (1967) found that the movement of juvenile pink shrimp in the water column of the Buttonwood Canal maximized on full moon ebb tides in early summer. Costello *et al.* (1986) summarizes the work done on the species from 1965 to 1968 by the National Marine Fisheries Service. They found that maximum concentrations of juvenile pink shrimp occurred in western Florida Bay; few occurred in eastern Bay. Juvenile shrimp occur year-round and are most abundant from late summer to early winter, in seagrasses. Flood tides (especially associated with a rise in sea level from about April to October) bring planktonic postlarvae into the Bay where they settle as epibenthic postlarvae (approximately 0.4 in [10 mm.]), actively selecting shoal grass for initial settlement. Optimum habitat for early juveniles consists of relatively open marine water circulation, with daily tide exchange, and broad intertidal and subtidal beds of shoal grass, with high blade density. With growth, late juvenile and early adult shrimp move to deeper water. Shrimp in the 2.76-3.15 in.(70-80 mm) range prefer channels and basins.

Robblee and Tilmant (1989) studied the seasonal abundance and recruitment of juvenile pink shrimp in Johnson Key Basin in western Florida Bay. The species was present throughout the year in the basin and was more abundant during fall and winter (peak, September and December). Shrimp in the less than 0.4 in. (9 mm) size class were the most abundant. Juvenile pink shrimp were most abundant in near-key habitats. They seem to prefer this near-key or bank habitat throughout the Bay.

Browder (1985) reports a relationship between freshwater runoff to estuarine areas in the Park, as indexed by water levels in the Shark River Slough, and landings on the Tortugas fishing grounds. A strong positive relationship was found between quarterly landings and average water level of the previous quarter. October through March shrimp landings (when two-thirds of the annual landings occur) were associated with high freshwater discharges from July through December. January through March freshwater discharges also positively affect the landings. An inverse relationship exists between landings and discharges from April through June.

Several documents report the importance of Florida Bay as nursery area for the spiny lobster (Davis and Dodrill, 1980; Lyons *et al.*, 1981; Marx and Herrnkind, 1986). Lobsters enter the Bay as actively swimming pueruli (postlarvae) and settle rapidly when they encounter suitable inshore substrate. Herrnkind and Butler (1986) have found that the alga *Laurencia* spp. is the preferred settling habitat of postlarvae, which may remain in that habitat as early juveniles (20 mm [0.8 in.]). Late juveniles and early adults occupy crevices in rubble areas, large sponges, coral heads, mangrove roots, seagrass bed undercuts, solution holes, and rocky outcrops or ledges. Lobsters approaching maturity (2.76-3.15 in. [70-80 mm]) emigrate offshore (Marx and Herrnkind, 1986).

Commercial fishing for stone crab was allowed in the Everglades National Park prior to 1985. Before that time, the fishery was showing signs of stock depletion and increased fishing pressure (Bert *et al.*, 1986). Bert *et al.* (1986) and Bert and Stevely (1989) summarize the biology and population dynamics of the stone crab in the Park. Relative abundance, proportion of females, and number of juveniles were highest in the Lostmans River area northward. Mean size of both sexes was smallest in that region. Southward and into Florida Bay, the relative abundance of both adults and juveniles decreased, the proportion of males increased, and the mean size of both sexes became larger. Juveniles were not found in Florida Bay. The primary source of adults in Florida Bay appears to be a very slow movement of crabs from the Gulf of Mexico progressively into the Bay. The crabs excavate burrows under emergent hard substrate or in turtle grass beds. Density is highest in mixed rock/seagrass habitat. Females prefer rock/seagrass, whereas males prefer mixed rock/sand habitat. In western Florida Bay, where little rock habitat exists, no difference in substrate preference between the sexes was noted.

Mangroves. A summary of information on mangroves in south Florida is presented by Odum *et al.* (1982). Most of the mangroves in Florida (estimated two thirds [Olmsted *et al.*, 1981]) are located within Everglades National Park, particularly in the Whitewater Bay/Shark River Slough and along the Gulf of Mexico shoreline northward. All three species--black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and red mangrove (*Rhizophora mangle*)--and the six community types--overwash, fringe, riverine, basin, hammock, and scrub or dwarf--exist within the Park. Overwash mangrove forests dominated by red mangroves are found on the islands in Florida Bay. Fringe mangrove forests are typically thin fringes along waterways and may contain all three species of mangroves in zones defined by tidal inundation. Riverine mangrove forests, probably the largest community in the Park, are found along the tidal rivers and creeks in the western portion of the Park; red mangroves predominate along the banks, with the other species found inland. Basin mangrove forests and hammock forests occur in areas where terrestrial runoff is being channeled to the tidal rivers or coast. Basin forests are found in depressions and are dominated by black and white mangroves. Hammock forests occur on slightly elevated areas and all three species may be present. Scrub or dwarf forests are found in the limestone substrate of the eastern portion of the Park. This community type may contain any of the three species and appears to be nutrient limited.

Davis (1940, 1943a) provided the first detailed descriptions of the mangrove forests of south Florida. Several of the classic studies on mangrove ecology (e.g., Heald, 1969; Heald *et al.*, 1974) were performed in the Whitewater Bay/Shark River Slough drainage basin. Olmsted *et al.* (1981) is the first attempt to use a combination of aerial photography and "ground truth" surveys to map the coastal vegetation from

Flamingo to Joe Bay and a transect through Coot Bay Hammock (Olmsted and Loope [1981] as reported in Olmsted *et al.* [1981]). The vegetational communities are delineated and described. The observed effects of hurricanes, fire, freezing, sea level rise, and human influences, including the introduction of the exotic Brazilian pepper (*Schinus terebinthifolius*), are discussed.

A discussion of the major values attributed to mangrove forests is contained in Odum *et al.* (1982). These include substrate formation, water quality alterations, nutrient cycling, leaf litter production, and fish and wildlife habitat. The formation of peat soils by mangroves has been extensively studied by geologists in the Florida Bay area (Cohen and Spackman, 1972; Cohen and Davies, 1989; also, see Section 2.5.2). Odum *et al.* (1982) summarize the current understanding of mangrove peat and soils: 1) mangroves can grow in a wide variety of substrates including mud, sand, rock, and peat; 2) mangrove ecosystems appear to flourish on fine-grained sediments that are usually anaerobic and may have a high organic content; 3) mangrove ecosystems that persist for some time in the absence of strong physical forces may modify the underlying substrate through peat formation; 4) mangrove peat is formed primarily by red mangroves and consists predominately of root material; 5) red mangrove peats may reach thicknesses of several meters, have a relatively low pH, and may be capable of dissolving underlying layers of limestone; and 6) when drained, dried, and aerated, mangrove soils experience dramatic increases in acidity due to the oxidation of reduced sulfur compounds. Olmsted *et al.* (1981) discuss the importance of mangroves as "land builders," stating that sea level fluctuations dwarf any effects of land buildup by peat formation. They consider the mangrove ecosystem as "steady-state," with the only major sediment accumulation occurring during storm events.

Odum *et al.* (1982) describe the surface water quality in mangrove forests as characterized by 1) a wide range of salinities from virtually freshwater to above 40 ppt, 2) low macronutrient concentrations (particularly phosphorus), 3) relatively low dissolved oxygen concentrations, and 4) frequently increased water color and turbidity. The last three become most pronounced in extensive systems such as those in the Whitewater Bay/Shark River Slough area. The low macronutrient concentrations have led to speculation concerning mangrove forests as nutrient sinks. These ecosystems appear to act as sinks for many elements, including nitrogen and phosphorus, as long as the input is modest. Nitrogen fixation may provide much of the nitrogen needed for mangrove growth.

The fall of mangrove leaf litter (and other parts of the tree), is an important ecosystem process because it forms the basis for detritus-based food webs in the mangrove forests (Odum *et al.*, 1982). Odum (1970) and Heald (1969), in their work on the North River estuary, estimated the litter production from riverine red mangrove forests averaged 2.4 g dw of organic matter/m^2/day (or 876 g/m^2/year). Riverine, fringing, and overwash communities produce the greatest litter fall. Mangrove leaves increase in nitrogen, protein, and caloric content as they decompose. Mangroves do export this material as dissolved or particulate organic carbon to adjacent bodies of water, particularly during extreme events such as storms.

Mangroves are important as fish and wildlife habitat, as indicated in the previous sections. Algae, sponges, and ascidians attach to the prop roots of red mangroves and provide habitat for amphipods, isopods, and algae (Rehm, 1974; Nickelsen, 1977; Odum *et al.*, 1982). Fish and shrimp use the root system as protective habitat. Many bird species nest in the canopies of the trees and feed in the surrounding waters.

Zieman (1982) emphasizes the importance of the juxtaposition of the two faunally-rich habitats, mangroves and seagrass, found in coastal Everglades National Park and Florida Bay. The individual studies have shown certain species interdependence on the two habitats. For example, gray snapper, spotted seatrout, and red drum recruit into the seagrass habitat, but move into the mangrove habitat for the next several years.

Wildlife. Most of the wildlife of the mangrove fringe of Everglades National Park and Florida Bay has been discussed within the preceding sections; for a synthesis of the faunal components of mangrove and seagrass systems in south Florida, see Odum *et al.* (1982) and Zieman (1982).

Within the amphibians and reptiles, two subspecies of diamondback terrapin use the mangroves as principal habitat, *Malaclemys terrapin macrospilota* and *M. terrapin rhizophorarum.* Four species of sea turtles have been documented as using Florida Bay; further discussion will occur under Endangered Species and Species of Special Concern. One species of snake, the mangrove water snake (*Nerodia fasciata compressicauda*), is dependent on mangrove habitats. The American crocodile (*Crocodylus acutus*) will also be discussed as an endangered species.

Birds are a major component of wildlife using mangrove and seagrass habitats surrounding Florida Bay, and have been studied by Everglades National Park personnel and National Audubon Society researchers. The U.S. Fish and Wildlife Service has provided summaries of marine birds in the southeastern U.S. and the Gulf of Mexico. Part I contains Gaviiformes through Pelecaniformes (Clapp *et al.*, 1982a); Part II, Anseriformes (Clapp *et al.*, 1982b); and Part III, Charadriiformes (Clapp *et al.*, 1983). The U.S. Fish and Wildlife Service has developed habitat suitability indices for the Laughing Gull (*Larus atricilla*) (Zale and Mulholland, 1985), the Brown Pelican (*Pelecanus occidentalis*) (Hingtgen *et al.*, 1985), and the White Ibis (*Eudocimus albus*) (Hingtgen *et al.*, 1985b).

The annual Coot Bay Christmas Count, a single day census of waterfowl over an area of 458 km^2 near Flamingo, has been held since 1951 and provides a large database for analysis. Bolte and Bass (1980) provides a reporting of this data up to 1979. Kushlan *et al.* (1982a,b) provides an analysis of wintering waterfowl counted up to 1981 in the Coot Bay count, along with surveys done by the U.S. Fish and Wildlife Service (data reported in Fritts and Reynolds [1981], Nesbitt *et al.* [1982], and Portnoy *et al.* [1981]), and Everglades National Park Service personnel (1977-1978 data reported in Bass, 1979). Blue-winged Teal (*Anas discors*), Lesser Scaup (*Aythya affinis*), Pintail (*Anas acuta*), American Widgeon (*Anas americana*), Ring-necked Duck (*Aythya collaris*), Northern Shoveler (*Anas clypeata*), Mottled Duck (*Anas fulvigula*), Green-winged Teal (*Anas crecca*), Ruddy Duck (*Oxyura jamaicensis*), and Red-breasted Merganser (*Mergus serrator*) have consistently accounted for greater than 90% of the wintering waterfowl along the coastal area of the Park.

Kushlan and White (1977a) surveyed 41 colonies of nesting wading birds in south Florida in 1974-1975; 21 of these colonies were located in Florida Bay and the contiguous mangrove areas within Everglades National Park. This report compared estimates of population with past estimates and found a 95% decrease in population of nesting birds since the 1800's, an 89% decrease since the 1930's, and a 13% decrease since 1970. Even the population within the Park, representing a protected site, has shown reduction, suggesting that aspects of the natural ecological processes are no longer functioning (Kushlan and White, 1977a).

Several individual bird species have been investigated within Florida Bay (Kushlan *et al.* [1978] provides a bibliography of wading bird investigations in South Florida). Kushlan *et al.* (1975) documents a relation between Wood Stork (*Mycteria americana*) nesting success and fluctuating water levels in the Shark River Slough. Historically, Wood Stork nesting success was associated with high summer water levels, high rates of surface water discharge, and high rates of drying. Fish on which the Wood Stork feeds increase in density during the dry season as water levels fall. Before the closure of the south side of Conservation Area 3 in 1962, years of successful and unsuccessful nesting were characterized by different patterns of drying. After 1962, the predictability of nesting success failed. Successful nesting occurred in only one nesting year (1967), and there was low production in 1971 and 1972. Lack of successful nesting can be attributed in part to late colony formation as a result of inability to attain a suitable nutritional state. Ogden *et al.* (1978) studied food habits and nesting success of Wood Storks within Everglades National Park in 1974. Since 1974 was a dry year, it continued the pattern of successful nesting during dry years. The time of nesting, January, correlated with drying in the Everglades. The diet of the Wood Stork was composed of fish, with marsh killifish (*Fundulus confluentus*), sheepshead minnow (*Cyprinodon variegatus*), flagfish (*Jordanella floridae*), sunfish (*Lepomis* spp.), and yellow bullhead (*Ictalurus natalis*) accounting for 84% of the fish eaten. Storks fed where food was relatively concentrated, and selectively consumed the relatively larger fish of those available. The 1974 results proved that sufficient food can still be produced in the highly altered south Florida environment to permit successful nesting of the remnant population of Wood Storks, although with loss of habitat and artificial impoundment of water, storks were forced to fly 130 km (81 mi) from the colony to feed the young late in the nesting season.

Kushlan and White (1977b) documented Laughing Gull colonies in Florida Bay during the summer of 1976. They documented 1,395 Laughing Gull nests at 15 sites on islands in Florida Bay. All colonies were in the interior of the islands on open marl flats or among low herbaceous plants (e.g., *Batis maritima, Sesuvium portulacastrum*). Colonies on Horseshoe Keys, East Key, and Nest Key contained 69% of the nests.

Kushlan and McEwan (1982) located and counted Double-crested Cormorant (*Phalacrocorax auritus*) colonies in Florida Bay during 1977-1978. They located 30 colonies, but 73% of the nests were concentrated in eight colonies. Year-round nesting occurred on Frank Key and Sandy Key in western Florida Bay.

Robertson *et al.* (1983) reported on the movement of juvenile Roseate Spoonbills (*Ajaia ajaja*) marked in Florida Bay in 1979. They recorded dispersion of up to 400 km (248 mi) in the first year.

Bass and Kushlan (1982b) report on the status of the Osprey (*Pandion haliaetus*) in Everglades National Park. Poole has studied sibling aggression among nestling Ospreys (Poole, 1979) and brood reduction (Poole, 1982). Ogden (1975) studied productivity and factors affecting nesting success in Ospreys. All of these studies find a reduction in nesting success of the Osprey, particularly on three islands in western Florida Bay--Murray, Frank, and Palm Keys--where a 63% reduction in nests occurred since 1968. Ogden (1975) attributed the reduction to competition with the Bald Eagle (*Haliaeetus leucocephalus*), and Poole (1979, 1982) attributed the reduction to food stress (decreased food supply) and, subsequently, increased sibling aggression. Bowman and Powell (1989) investigated variations in reproductive success between subpopulations of the Osprey. They compared nesting populations in

Florida Bay to populations in the lower Florida Keys and found greater foraging success of Lower Keys' nests came from trips to the Atlantic Ocean rather than Florida Bay. They concluded that decrease in Florida Bay nesting success was due to inadequate food supply. Fleming and Kline (1989) have compared nesting distribution, abundance, and success of the Osprey from 1968 to 1984. They report that current Osprey productivity occurs primarily on islands adjacent to the mainland coast of northern Florida Bay. An apparent relationship exists between annual rainfall and salinity variability, the relative abundance of important fish prey species, and subsequent Osprey productivity.

Powell and Powell (1986) related reproductive success of Great White Herons (*Ardea herodias*) to food supply in Florida Bay and found that clutch size is significantly smaller and there are significantly fewer fledglings than in 1923. They interpret the data as indicating that habitat quality is currently reduced from 1923 levels. Powell (1987) analyzed habitat use by wading bird species with respect to fluctuating water levels within the Bay and found that many alternative foraging sites in eastern Florida Bay that are not within the Park boundary are susceptible to human impacts.

G.V.N. Powell *et al.* (1989b) analyzed population trends of the wading birds Roseate Spoonbills, Reddish Egrets (*Egretta rufescens*), and Great White Herons in the Bay. All three species are believed to have had relatively large populations in the Bay but were harvested for their feathers in the late 1800's and early 1900's to virtual extirpation. All species have recovered to a much lower density than was historically present, and in recent years Roseate Spoonbills have shown a population decline and the Great White Heron has demonstrated low reproductive success.

No terrestrial mammals are confined to the mangroves of south Florida. Odum *et al.* (1982) contains a complete listing of mammals that have been sighted in south Florida mangroves. The most common species include opossum (*Didelphis virginiana*), marsh rabbit (*Sylvilagus palustris*), cotton rat (*Sigmodon hispidus*), black rat (*Rattus rattus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), bobcat (*Felis rufus*), and white-tailed deer (*Odocoileus virginianus*).

Schmidly (1981) compiled the known distribution of marine mammals found living within Everglades National Park, using data reported by Moore (1953), Layne (1965), and Fritts and Reynolds (1981). Species found in the Park area include a fin whale (*Balaenoptera physalus*) located near Man-o-War Key; a sperm whale (*Physeter catodon*) located near the north entrance to Whitewater Bay; several short-finned pilot whales (*Globicephala macrorynchus*) located along the Gulf coastline of the Park up to 13 km (8 mi) up Shark River and near Cape Sable; and the Atlantic bottlenose dolphin (*Tursiops truncatus*) located throughout the Park area. Odell (1975) documented the status of the Atlantic bottlenose dolphin in the Park, using a series of overflights conducted in 1973-1974. He reported an increase in the number of dolphin in Florida Bay and Whitewater Bay during winter months, possibly related to calving/mating season or seasonal changes in food distribution or water temperature. Irvine *et al.* (1981) reported the results of a 1979 aerial survey of the Park for manatees, dolphins, sea turtles, and crocodiles. They noted a high number of dolphin calves in the Park area in December. The West Indian manatee will be discussed as a threatened and endangered species.

Food Web Interactions and Ecosystem Productivity. The hypothetical framework for energy flow through mangrove and seagrass communities is understood qualitatively. The best understood systems are those where the bulk of the research has occurred--e.g., the mangroves of the Whitewater Bay, Shark River, and North River area and the seagrass beds of Florida Bay. It is also important to recognize that there are interactions and connections between seagrass and mangrove ecosystems, and that Florida Bay ecosystems influence the surrounding areas (e.g., by exporting detritus, or by serving as nursery areas for species that eventually migrate to surrounding areas).

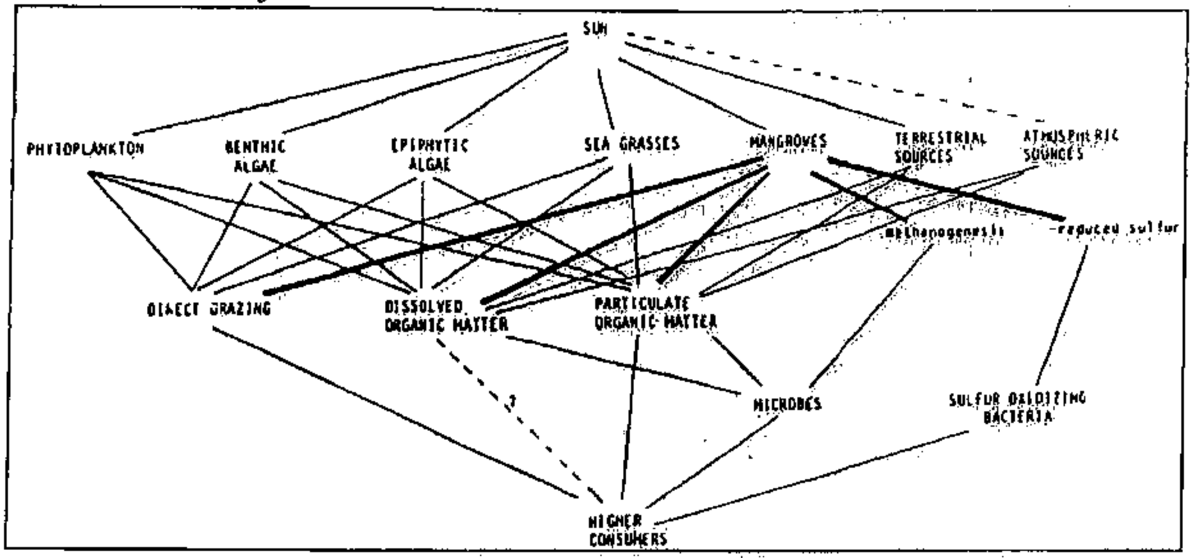
The importance of detritus in the riverine mangroves around Whitewater Bay has already been mentioned. Odum *et al.* (1982) report at least seven sources of carbon serve as energy inputs to consumers in mangrove ecosystems (**Figure 73**). The relative importance of these energy sources varies from one location to another. Consumers in riverine mangrove communities appear to be dependent on mangrove-derived carbon, whereas consumers in overwash communities are more dependent on phytoplankton and attached algae. In other locations, phytoplankton, zooplankton, and larval fish may be the predominant food web. In general, there is very little direct grazing of mangrove leaves.

Heald (1970) traced the production and transport of organic detritus in the North River estuary and Odum (1970) documented the food habitats of 53 species of fish and numerous invertebrates using the estuary. **Figure 74** is a summary of the energy flow in this community. Heald (1971) estimated that 85% of the "debris" (=detritus) produced in the North River estuary originated from the red mangrove. The mangrove detritus is broken down by detritus consumers (invertebrates, e.g., caridean shrimp, crabs, mollusks, insect larvae, amphipods, and small fish). The best environment for the degradation of mangrove detritus is a system well moderated by adequate freshwater and/or tidal flushing (Schomer and Drew, 1982). Heald (1971) documents microbial (bacterial and fungal) succession on red mangrove leaf detritus during this degradation process. This successional process leads to the relative enrichment of the leaf, with animal protein at the expense of plant protein giving the leaf higher nutritive content for detritus consumers. Blum *et al.* (1988) conclude that the microorganisms may not be the primary source of carbon for detritus consumers, but they may be a major source of essential nutrients such as fatty acids, amino acids, sterols, vitamins, and other growth factors. The most important pathway in a detritus producing mangrove ecosystem is mangrove leaf detritus --> microbial enrichment --> detritus consumer --> higher consumers (Odum *et al.*, 1982). These higher consumers can be terrestrial (e.g., mammals and birds) or aquatic (e.g., fish and larger invertebrates) in origin.

Depending on the intensity of freshwater outflow and/or tidal flushing, the detritus can leave the mangrove ecosystem and influence the surrounding waters (*e.g.*, Florida Bay), or accumulate and begin the sedimentation process. Nitrate and sulfate are highly important as oxidants in the anaerobic decomposition of mangrove detritus. Sulfides, the product of sulfate decomposition, may combine with heavy metals, magnifying the background load in mangrove sediments.

Seagrasses (and associated epiphytes) provide food for higher trophic level consumers by 1) direct herbivory, 2) detrital food webs within the seagrass beds, and 3) exported material that is consumed in other systems as plant matter or detritus (Zieman, 1982). The importance of any one mode of utilization may be location specific; however, the detrital pathway is the primary pathway of trophic energy transfer. Manatee, sea turtles, fishes (e.g., parrotfish [*Sparisoma* spp.]), sea urchins, crustaceans, and molluscs (e.g. queen conch [*Strombus gigas*]) have been noted as direct consumers of seagrasses (for a complete listing see Zieman, 1982). In addition, amphipods and isopods may be direct consumers of epiphytes on the seagrass blades.

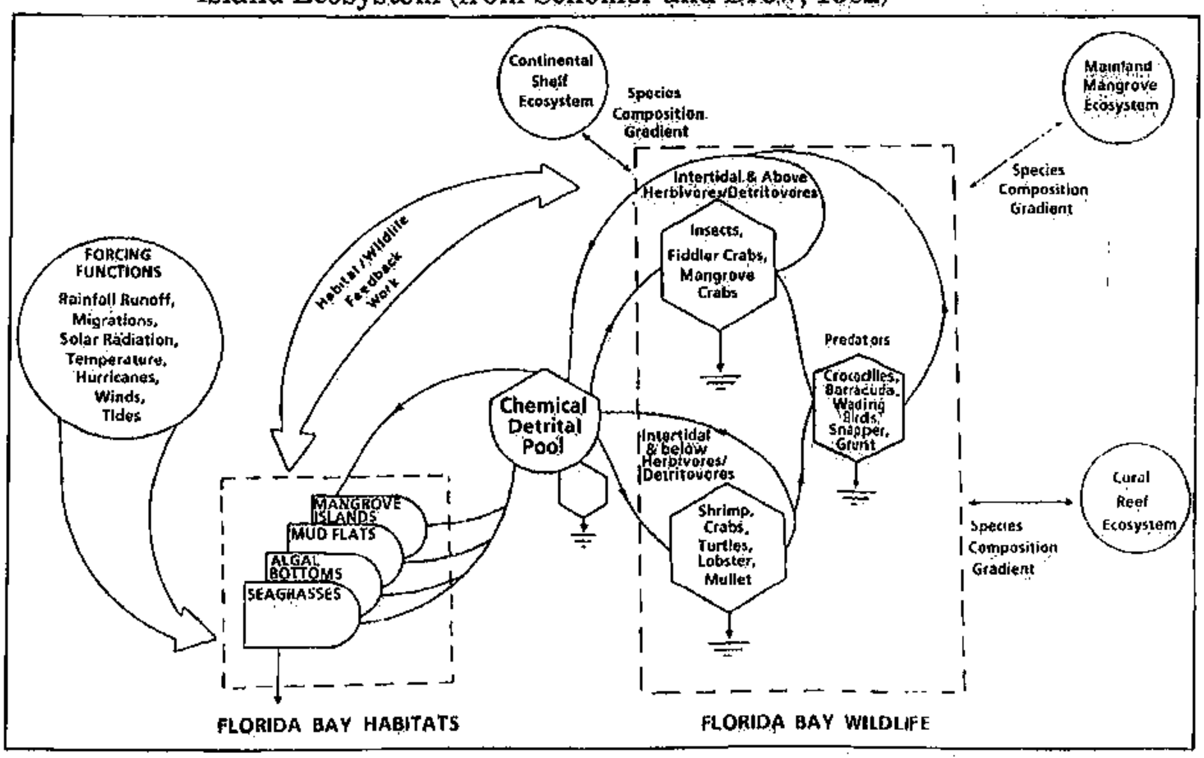
Figure 73. Potential Pathways of Energy Flow in Mangrove and Seagrass Ecosystems.



Source: Odum *et al.*, 1982

As with mangrove detritus, fresh seagrass detritus is not usually used as a food source. Breakdown of plant fiber and, increase in nutritional value due to increase in microbial biomass, occur with decomposition (Blum *et al.*, 1988). The nutritional contribution to higher trophic levels by seagrass detritus does not have to occur in the seagrass beds. Currents can carry the detritus from the bed to surrounding waters or sea bottom to enrich those areas.

Figure 74. Summary Diagram of Energy Flow through the Florida Bay/ Mangrove Island Ecosystem (from Schomer and Drew, 1982)



Source: Schomer and Drew, 1982

There are many similarities and interactions between mangrove and seagrass communities. Several fish species have been noted as living different stages of their life history in a particular habitat. The coral reef community also interacts in this manner with these two communities. Several fish species and the spiny lobster spend juvenile stages in seagrass or mangrove habitats, and certain fish species migrate diurnally or seasonally between these habitats. These interactions may be regionally important in Florida Bay. For example, coral reef-seagrass interaction is more important in the southeastern portion where passes to the Atlantic exist, whereas mangrove-seagrass interaction is more important in the northwest portion.

Threatened Natural Resources. This section is a discussion of the fish, wildlife, and natural vegetation that is being or may be impacted by deteriorating water quality. Surface water and/or groundwater originating from three sources flowing into Florida Bay has had an effect on the Florida Bay ecosystem. These three sources are; 1) modified flow to the Shark River Slough through the S-12 gates, 2) modified flow to the eastern side of the Park through the C-111 Canal and into Barnes Sound, and 3) surface water and groundwater flow from the Florida Keys.

The effects of the modified flows through the Shark River Slough have been mentioned throughout the text as affecting important fisheries species and endangered species (*e.g.*, the Wood Stork). The alteration of freshwater inflow to the Park through the Shark River Slough has been the focal point of much of the research occurring in that area. Reduction in freshwater flows was implicated in the decline of estuarine fisheries in the area during the 1970's. (Schmidt, 1988, personal communication, Everglades National Park) has compared salinity values from past studies (Tabb *et al.*, 1962; Clark, 1971; Davis and Hilsenbeck, 1974) with those from 1979 to 1983 and suspects a possible dampening of salinity fluctuations (*i.e.*, the average salinity has not changed but the highs and lows are less). Discharges of excessive amounts of freshwater, especially during periods that are normally dry, have been blamed for adverse changes in freshwater plant and animal communities upstream of the estuary (VanArman, 1984).

Heald (1970) asserts that the runoff from the central Everglades toward the estuary to the south was formerly (pre-drainage) about 2.3 million acre-feet (2.8×10^9 m^3) in average rainfall years and as high as 10.7 million acre-feet (1.3×10^{10} m^3) in peak years. Following completion of the major drainage projects in the watershed by 1944, records of annual runoff in the same area averaged less than 500,000 acre-feet (6.2×10^8 m^3), rising to 1.4 million acre-feet in the peak rainfall year of 1947. The U.S. Geological Survey (Klein *et al.*, 1975) compared the flow to the Park before and after the construction of the S-12 control structures in Levee 29 and report that discharge before construction (1941 to 1962) from Conservation Area 3 through outlets in the Tamiami Canal between Levee 30 and 40-Mile bend averaged 372,000 acre-feet (4.6×10^8 m^3) per year and discharges after construction through S-12 averaged 548,000 acre-feet (6.8×10^8 m^3) per year (1963 to 1970) and 456,000 acre-feet (5.6×10^8 m^3) per year (1971 to 1980).

As described by Ogden (1988a), the problem is one of both insufficient quantity of water but also concentration of the water source. This has prevented efficient sheet flow through the system, causing some areas to be inundated with water and peripheral areas to be dry, essentially decreasing the production of food, small fishes, and macroinvertebrates in the freshwater areas required for successful nesting. An example is the Wood Stork, which now seldom successfully nests except in dry years when the wettest portion of Shark River Slough experiences drying. Prior to changes in water delivery, most nest failures occurred in dry years. Wood Storks have nested successfully 7 of 10 years between 1953 and 1962 but only 7 of 25 years between 1963 and 1988. Ogden (1988a) documents three basic changes in wading bird nesting patterns in the Park:

1) Wading birds have shifted timing of nesting. For example, Wood Storks shifted initiation of nesting from November-December to February-March, and small herons, egrets, and ibis, from February-March to March-April in mainland colonies.
2) Some wading birds, e.g., small herons, egrets, and White Ibis, have changed locations of colonies, since the late 1960's, from the traditional colony sites in the mangrove forest and in the mangrove-marsh ecotone at the end of the Shark River Slough to Water Conservation Area-3A.
3) Wading birds have shown a reduction in frequency of successful nesting.

Several sport and commercial fish species, including snook, spotted seatrout, and red drum, show increased recruitment following high rainfall and high release of water to the estuary. Browder (1985) reported a strong positive relationship between quarterly landings of pink shrimp on the Tortugas fishing grounds and the average water level of the previous quarter. Shrimp landings from October through March (when two-thirds of the annual landings occur) were associated with high freshwater discharges from July through December. January through March freshwater discharges also positively affect the landings. An inverse relationship exists between landings and discharges (water levels) from April through June.

Lack of delivery of freshwater to central Florida Bay may be the cause of periods of hypersalinity (e.g. salinity of 45 to 65 ppt in 1974 to 1975), fish kills (both forage fish and juvenile sport fish, and the current seagrass die-off (Schmidt, 1988, personal communication, Everglades National Park). These problems may be the result of long-term lack of freshwater entering the system; however, the short-term release of freshwater by removal of the S-197 has resulted in severe impacts to the marine ecosystem in Manatee Bay and Barnes Sound. The S-197 consists of a 3-barrel, 84-inch pipe culvert with manually operated gates and an adjacent earthen plug. The earthen plug has been removed on five occasions; four of those occasions were for upstream control during major storms: 18-27 August and 27 September to 5 October 1981 (Tropical Storm Dennis), 3-5 June 1982, and 23-24 July 1985 (Tropical Storm Bob). The recent release of water in August 1988 caused extremely low salinity in Manatee Bay and Barnes Sound, fish kills, and sponge die-off.

The entire Florida Keys shoreline adjacent to the Park can be considered a non-point source of pollution. The major source of pollution in the Florida Keys is on-site sewage disposal systems (septic tanks and aerobic treatment units) with effluents to surface or groundwater. Lapointe and O'Connell (1988) studied the effects of on-site sewage disposal systems on nutrient concentrations of upland groundwaters and adjacent inshore waters of the Florida Keys. They found that the systems result in extremely elevated nutrient concentrations in groundwaters. Maximum concentrations in groundwater nutrients occurred during winter, whereas maximum concentrations in surface waters occurred during summer. The inverse seasonal pattern suggests that the maximum discharge of groundwaters occurs during summer (rainy season).

Endangered Species and Species of Special Concern. Table 92 lists endangered, threatened, and other species of special concern that may occur within coastal ENP. Most of the species on this list are endangered, threatened, or of special concern because of loss of habitat or the ability to use the habitat. Development pressures have squeezed many species into habitats that exist within National, State, and local parks. At the same time these areas area heavily used for recreation. Two very important habitat species--the black and red mangroves--fall into this category. A large percentage of the mangroves in Florida are in Everglades National Park. Three other seashore plants (*Euphorbia garberi* [type locality the back-beach of Cape Sable], sea-lavender, and Florida thatch palm) or salt marsh (manchineel) plants have been limited to certain areas including the Park by development.

The total number of manatees *(Trichechus manatus)* in Florida is estimated to be at least 1,465, a population which is roughly equally split between the Atlantic and Gulf coasts (with slightly more animals on the Atlantic coast). This population count is based on a synoptic aerial survey of the state's manatee population performed by DNR in February 1991. There is marginal interchange between the east and west coast populations. The greatest known causes of manatee mortality are human related; of these, collisions with watercraft account for about 80% of the deaths. Irvine *et al.* (1981) surveyed manatees of the west coast of Florida. ENP represents the southern limit of that population. They noted several individuals entering Whitewater Bay in the winter months. More recently, biologists at ENP have performed manatee surveys.

Any of the sea turtle species found in the Caribbean may use Florida Bay as foraging habitat, except the Olive ridley (*Lepidochelys olivacea*). The Kemp's ridley sea turtle has been reported as migrating through the area (Robertson, 1989; McVey and Wibbels, 1984). The loggerhead has nested within the Park (Holden, 1964, 1965; Klukas, 1967; Davis and Whiting, 1977). Davis and Whiting (1977) reported between 600 and 1,200 nests on Cape Sable in 1972-73. Nesting also occurred on Sandy Key, Shark Point, Highland Point, Lostmans Beach, Hog Key, Plover Key, North Plover Key, Turkey Key, New Turkey Key, Mormon Key, Pavilion Key, and Rabbit Key.

Most of the American crocodiles occur from extreme southern Biscayne Bay south and west along the mainland and Key Largo shorelines of Card Sound and Barnes Sound, Lake Surprise, Blackwater Sound, Buttonwood Sound, and through eastern and central Florida Bay as far west as a line drawn from Plantation Key through Russell Key, Samphire Keys, to McCormick Creek on the mainland (Pritchard, 1978). Primary nesting sites in that area are either in the edge of hardwood thickets at the heads of small sand beaches, or on relatively high marl banks of narrow, coastal creeks. Ogden (1978b,c) reported on the status and nesting biology of the crocodile and suggested three reasons for lack of increase in the population: 1) the individuals being killed in the Key Largo area (accidents and poaching) are greater than recruitment of young; 2) mediocre nesting success due to failure of eggs to hatch rather than excessive predation; and 3) low nest temperatures in shaded areas. Dunson (1980, 1982) studied osmoregulation in crocodiles and found the skin virtually impermeable to sodium and hatchlings remain terrestrial for a period of time to prevent loss of body weight from contact with seawater. Lutz and Dunbar-Cooper (1982, 1984) found two basic nest environments of the crocodile in sand/shell and marl. Each environment had different gas diffusion leading to adaptation problems for the embryo. Both desiccation and flooding of the nests may cause egg mortality (Mazzotti *et al.* 1988). Stoneburner and Kushlan (1984) presented more recent data concerning heavy metal burdens in crocodile eggs, as a follow up to the work of Ogden *et al.* (1974). They reported the levels of several heavy

Table 92. List of endangered species found within the coastal Everglades National Park.

Common Name	Scientific Name	Designation Federal	Designation State
PLANTS			
(No common name)	*Euphorbia garberi*	t	nl
Manchineel	*Hippomane manchinella*	nl	t
Sea-lavender	*Mallotonia gnaphalodes*	nl	t
Florida Thatch Palm	*Thrinax floridana*	nl	t
Black Mangrove	*Avicennia germinans*	nl	sc
Red Mangrove	*Rhizophora mangle*	nl	sc
MAMMALS			
West Indian manatee	*Trichechus manatus*	e	e
REPTILES			
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	e	e
Leatherback Sea Turtle	*Dermochelys coriacea*	e	nl
Green Sea Turtle	*Chelonia mydas*	t	e
Loggerhead Sea Turtle	*Caretta caretta*	t	t
Atlantic Hawksbill Sea Turtle	*Eretmochelys imbricata*	e	e
American Crocodile	*Crocodylus acutus*	e	e
BIRDS			
Wood Stork	*Mycteria americana*	e	e
Eastern Brown Pelican	*Pelecanus occidentalis carolinensis*	e	t
Rothschild's Magnificent Frigate-bird	*Fregrata magnificens rothschildi*	nl	t
Bald Eagle	*Haliaeetus leucocephalus leucocephalus*	e	t
Osprey	*Pandion haliaetus*	nl	t
American Oystercatcher	*Haematopus palliatus*	nl	t
Least Tern	*Sterna albifrons*	e	t
White-crowned Pigeon	*Columba leucocephala*	nl	t
Reddish Egret	*Dichromanassa rufescens*	nl	r
Roseate Spoonbill	*Ajaia ajaja*	nl	r
Mangrove Cuckoo	*Coccyzus minor*	nl	r
Antillean Nighthawk	*Chordeiles minor vicinus*	nl	r
Black-whiskered Vireo	*Vireo altiloquus*	nl	r
Cuban Yellow Warbler	*Dendroica petechia gundlachi*	nl	r
Great White Heron	*Ardea herodias occidentalis*	nl	sc
Little Blue Heron	*Florida caerulea*	nl	sc
Great Egret	*Casmerodius albus*	nl	sc
Snowy Egret	*Egretta thula*	nl	sc
Louisiana Heron	*Hydranassa tricolor*	nl	sc
Glossy Ibis	*Plegadis falcinellus*	nl	sc
White Ibis	*Eudocimus albus*	nl	sc
Piping Plover	*Charadrius melodus*	t	sc
American Avocet	*Recurvirostris americana*	nl	sc
Royal Tern	*Sterna maxima*	nl	sc
Sandwich Tern	*Sterna sandvicensis*	nl	sc
Black Skimmer	*Rynchops niger*	nl	sc
Florida Clapper Rail	*Rallus longirostris scottii*	nl	su
Mangrove Clapper Rail	*Rallus longirostris insularum*	nl	su

e = endangered; t = threatened; r = rare; sc = species of special concern;
su = status undetermined; nl = not listed.

metals in the shell and albumin-yolk mass and found a mean decrease in cadmium, no change in mean copper concentration, and mean increases in lead and mercury. No literature exists on the sensitivity of crocodiles to heavy metal.

The reductions in populations of the birds listed in this region are directly related to perturbations by humans, most significantly, development pressures in nesting and foraging habitat. The Wood Stork is unique because the lack of nesting success in the Park can be directly related to a shift to later dates of colony formation (colonies initiated after mid-February will run well into rainy season and predictably fail). This closely coincides with completion of the water management system influencing water delivery to the Park. With L-67 and its extension in place and water releases to the Park portion of Shark River Slough entirely through the S-12 gates, large areas of former foraging habitat became relatively useless to Wood Storks. Areas isolated from the natural system, such as Conservation Area 3B and the East Everglades, tended to be too dry too often to be forage areas for Wood Storks. Former heavily-used foraging grounds in southern Conservation Area 3A and Shark River Slough were often deeply inundated and unavailable to storks for feeding until late in the dry season, if at all. Through the 1960's, most nesting failures of Wood Storks occurred in dry years; since 1970, under both the "minimum delivery schedule" and the "rainfall-driven model," storks have seldom managed to nest successfully except in dry years. Restoration of the Wood Stork breeding population in the Park requires reestablishment of the early-season foraging areas to promote nesting early enough for the young to fledge before the onset of rainy season and predictable later season foraging areas (Robertson, 1989).

Rothchild's Magnificent Frigate-bird nest only on the Marquesas Keys in Florida but forage in Florida Bay. The population is stable but susceptible to human disturbance. Several of the larger birds of prey (Eastern Brown Pelican, Bald Eagle, and Osprey) became endangered due to chlorinated pesticide contamination from the late 1940's through the 1960's. High levels of these persistent chemicals resulted in thinning of egg shells and caused drastic declines in productivity. Since the banning of those pesticides, the numbers of these birds has increased (Robertson, 1989; Pritchard, 1978). More recently, there is concern that the numbers of these and other fish eating birds (Roseate Spoonbill, American Avocet, Black Skimmer, egrets, and herons) may be affected by general deterioration of estuarine productivity due to changes in the natural regimes of upland flow. Ogden (1975) reports territorial aggression between eagles and ospreys in western Florida Bay and Poole (1979) reports food stress causing sibling aggression in nestling Osprey.

Many of the species are becoming endangered and limited to areas such as the Park because development is encroaching upon and reducing, and humans are disturbing, their nesting and/or foraging grounds. The American Oystercatcher, Black skimmer, and terns depend upon the beach and salt barren habitat for nesting and/or foraging. The White-crowned pigeon, Mangrove Cuckoo, Black-Whiskered Vireo, Cuban Yellow Warbler, pelicans, Ospreys, ibis, herons, and egrets reside in the mangrove forests. Both rail species are found in salt marsh and mangrove habitats. The herons, egrets, avocets, and spoonbills depend upon nearshore, shallow water for foraging. Populations of these species will not increase without expansion of these habitats.

Exotic Vegetation. Once established, exotic or non-native plant species have a number of detrimental effects on native plant and animal communities. They may force out native plant species by overshadowing, changing the soil chemistry, or drying out the soil via transpiration. They may disrupt the nesting of such substrate-dependent animals as the Gopher Tortoise, sea turtles of all types, the North American Crocodile, and various ground nesting birds. They may also impact the feeding and food supply of wading birds and other wetland foraging animals.

Currently, three exotic plant species are invading the mangrove fringe and islands of Everglades National Park: *Casuarina equisetifolia*--Australian Pine, *Schinus terebinthifolius*--Brazilian Pepper, and *Colubrina asiatica*--lather leaf. Only Australian Pine and Brazilian Pepper are currently target species for direct eradication by the Everglades National Park's exotic plant species control program.

Australian Pines are particularly detrimental to the sandy beaches of Cape Sable and many of the small islands in Florida Bay. Their growth pattern promotes increased beach erosion, and their roots choke off the beach as a nesting area for birds and such important endangered species as sea turtles and the North American Crocodile. The Australian Pine invasion of Everglades National Park has had two major entrance points. Along the southeastern boundary of the Park, Australian Pine have moved in from the disturbed areas outside the Park boundary. Probably beginning with railroad, then highway construction in the early 1900's, this process continues today. On the western side of the Park and in Cape Sable, Australian Pine infestations first appeared after Hurricane Donna in 1960. That storm transported seeds and branches across Florida Bay to the Everglades from the Florida Keys.

Because of the habitat and dispersal method of the Australian Pine, the National Park Service has had some success in controlling its spread within the Park boundaries. Australian Pine stands have been eliminated in the Cape Sable area and from some of the major islands in Florida Bay. Unfortunately, the removal of one stand or colony does not prevent an area from becoming reinfected, and exotic species control is a continuing effort throughout Everglades National Park.

Brazilian Pepper is dispersed primarily by birds who eat the shrub's fruit and then deposit its seeds with their droppings. An opportunistic species like the Australian Pine, the Brazilian Pepper has become widespread in disturbed areas. Within the mangrove fringe of Everglades National Park, it has become well established in mangrove stands damaged by frost or hurricanes. Unfortunately, there exists a vast reservoir of Brazilian Pepper within Everglades National Park itself in the old "Hole in the Doughnut" area. Many species of birds, particularly robins, come to this area of the Park to feed during their overwintering stay, and consequently Brazilian Pepper seeds are spread over a wide area annually.

Lather leaf is an overstory, vine type shrub found growing over native vegetation in coastal habitats. Because of its growth form, it is very difficult to control by the conventional methods of spraying or stem cutting. A native of southeast Asia, lather leaf is thought to have been introduced into the West Indies by Indian plantation workers. Its seeds are water dispersed and salt resistant, suggesting a sea route for its colonization of the coastal and island habitats in Everglades National Park. At present, the National Park Service is noting areas where lather leaf is established and hopes to monitor its rate of spread or regression.

Although not present in the mangrove fringe within the Everglades National Park, the Punk or Cajeput Tree (*Melaleuca quinquenervia*) is considered to be the greatest danger to the Park (Doren, R, 1988, personal communication, Everglades National Park, Exotic Plant Species Control). This species invades swamps and low-lying woodlands across south Florida and chokes out all other species once established. It is present in certain parts of the Keys within this study area, but its distribution there has never been mapped. Everglades National Park personnel maintain a constant watch for this species within the boundaries of the park, and to date their efforts have prevented the Punk Tree from becoming established to any great extent within the Park proper.

The relatively undisturbed natural plant communities of ENP represent an island of native plant communities ringed in by the disturbed lands of south Florida. The National Park Service, SFWMD, Dade County Department of Environmental Resource Management, and Exotic Pest Plant Counsel are working to maintain East Everglades as a buffer zone to prevent further contamination of Everglades National Park with exotic plant species from urbanized areas to the east.

Areas in Need of Special Protection or Preservation. Four areas within the study area have been shown to require special protection or preservation:

1) Rookery and foraging areas used by wading birds in the freshwater and mangrove fringe areas of Everglades National Park;
2) The Florida Bay shoreline of the Florida Keys;
3) L-31W and upper Taylor Slough;
4) Manatee Bay and Barnes Sound and adjacent estuarine areas need protection from the effects of large freshwater releases.

Of particular note is the decline in nesting wading birds. **Table 93** presents estimates by Ogden (unpublished) of the decline in nesting wading birds since 1930. Roseate Spoonbills have demonstrated a similar decline, particularly in the C-111 basin (Ogden *et al.*, 1989). The recovery of the nesting populations will require protection and preservation of the rookery and foraging areas. The rookery areas are within the mangrove fringe. The foraging areas are the freshwater Everglades, including East Everglades.

Table 93. Estimated numbers of nesting wading birds in the Everglades Region, Florida--1930's-1980's (From: Odgen, 1988b).

Species	1930's	1960's (% Decline)	1980's (% Decline)
Great Egret	15,000	8,000 (47%)	4,000 (73%)
Small Herons	40,000	20,000 (50%)	6,000 (85%)
White Ibis	200,000	50,000 (75%)	8,000 (96%)
Wood Stork	8,000	6,000 (25%)	500 (93%)
Totals	263,000	84,000 (68%)	18,500 (93%)

The waters adjacent to the Florida Keys are in need of special protection from the assault of rapid growth and poor planning. This area is an Area of Critical State Concern by the Governor and Cabinet and has been classified as Outstanding Florida Waters by the DER, but still no efforts exist to curtail the discharge of partially treated wastewater into ground and surface waters. The Florida Keys National Marine Sanctuary and Protection Act was signed into law on November 16, 1990 and requires the EPA and the State of Florida to develop a Water Quality Protection Program for the Sanctuary, which consists of 2,600 square nautical miles of coastal waters. Lapointe and O'Connell (1988) have recommended that baseline studies be done to assess the current situation. Currently, little information is available to document the extent of eutrophication in the nearshore waters of the Florida Keys.

The study should address subtle increases in nutrients and chlorophyll in the nearshore waters, including both temporal (seasonal) and spatial (high and low density areas in the Keys) variability of water quality in the generally oligotrophic waters of the Keys. The results of the study should be used for future planning and permitting in the Keys. Centralized wastewater collection and treatment is required to assure adequate nutrient removal. Alternative methods of disposal of wastewater should be considered. Education programs should be aimed at lowering the per capita loading rates in wastewater and from lawn fertilizers, road runoff, and marinas.

These two proposals for protection seem to be in conflict when one considers the recent study by Powell *et al.* (1989a). In that study, the authors demonstrated that phosphorus is the limiting nutrient to seagrass growth on Cross Bank and that the input of bird excrement can provide phosphorus, causing nitrogen to become limiting. The study showed that birds do provide a substantial amount of nutrients to Florida Bay. This fact is particularly significant considering the populations of most bird species have experienced dramatic declines in recent years; many species currently exist in numbers that represent less than 10% of past populations (**Table 93**). Powell *et al.* (1989a) demonstrate significant positive responses of seagrasses to bird excrement. Rookery areas are found in the tallest and greenest trees in the mangrove fringe (Ogden, J.C., 1989, personal communication, Everglades National Park). Certainly, some areas of Florida Bay may be showing signs of deprivation of this nutrient source and will benefit from increased bird usage. The shoreline of the Florida Keys, however, is showing signs of gradual eutrophication from poor wastewater and surface water management practices. It is important to understand that interior Florida Bay is a naturally low nutrient environment and areas along the Keys can have problems related to increased nutrients or sewage contamination

Areas Currently in Need of Restoration. The recovery of nesting populations of wading birds in the headwaters and mangrove fringe regions of Shark River Slough requires the reestablishment of a larger, long hydroperiod in the slough south of the Tamiami Trail. This area should dry less frequently than the current unnatural pool that exists west of the L-67 extended. Reestablishment of earlier colony formation, especially by wood storks, requires more food, produced in more areas. Longer hydroperiods and more extensive rainy season flooding (and conversely reduced frequency of complete dry-outs) are required throughout the system, including East Everglades (Ogden, 1988a). Information suggests that increased discharge of water into the estuarine system may increase recruitment of red drum (Tilmant *et al.*, 1989), snook, and sea trout (Rutherford *et al.*, 1989). Browder (1985) reported a positive relationship between pink shrimp landings on the Tortugas fishing grounds and increased freshwater discharges during the rainy season. Re-establishing former hydrologic patterns in the Shark River Slough/ Whitewater Bay system may aid the recovery of the populations of many species.

The scientific evidence indicates that conditions within the Everglades/Florida Bay ecosystem are deteriorating. Wading bird populations are down at least 90% since the 1930's because drainage projects have removed the sheet flow which once seasonally allowed the development of food resources within the foraging grounds of these species (Kushlan *et al.*, 1975; Kushlan and White, 1977a; Ogden *et al.*, 1978; Powell and Powell, 1986; Powell, 1987; Ogden, 1988; Powell *et al.*, 1989b; Ogden *et al.*, 1989; Ogden, 1989a; Robertson, 1989). Sea bird and osprey populations are down because food supplies in Florida Bay are no longer adequate to supply original population levels (Ogden, 1975; Poole, 1979, 1982; Bass and Kushlan, 1982; Bowman and Powell, 1989; Fleming and Kline, 1989). The upper and central areas of Florida

Bay have become stressed environments because salinities there normally reach 40 to 65 ppt in the summer and experience extreme temperatures (Tabb *et al.*, 1962; Tabb, 1967; Heald, 1970; Thomas, 1974; Schmidt and Davis, 1978; Robblee, 1989). Many marine organisms cannot survive in these conditions.

The capacity of Florida Bay to serve as an important nursery ground species such as pink shrimp, Florida lobster, seatrout, snook, redfish, grouper, and snapper has been greatly reduced. The Tortugas shrimp fishery that was once dependent upon pink shrimp from Florida Bay, has declined drastically during the 1980's (Browder, 1985; Rockland, 1988; South Florida Business Journal, 1989). Sports and commercial fish catches both within Florida Bay and along the southwestern Florida coast have decreased as habitat has deteriorated in Florida Bay (Browder, 1985; Rockland, 1988; Tilmant *et al.*, 1989; Rutherford *et al.*, 1989). These habitat losses represent real dollar losses to the south Florida economy. More importantly, they show the deteriorated state of an extremely valuable natural resource. Commercial fishery losses alone run into the millions of dollars (Rockland, 1988) and these losses can or will eventually be extrapolated into losses for the sport fishing industry, the boating industry, and eventually the tourist industry itself.

The bulk of wastewater effluent in the Keys undergoes secondary treatment, and is non-point source domestic waste, generated from package treatment plants and septic tanks that serve residential and commercial land uses. With the exception of two facilities, listed in **Table 88**, package treatment plants discharge to boreholes and injection wells (FDER, 1989). There is currently no information on the migration patterns, concentration, constituents, or impacts of wastewater effluent from package treatment plants with borehole or injection well disposal designs. The Monroe County Comprehensive Plan cites a series of technical memoranda originating from the Marathon office of the DER which evaluate sewage flows and effects from point source surface discharges in the vicinity of Key West. Stated results were that no significant contamination occurred. There is currently only one study on the migration of septic tank effluent in the Keys (Lapointe and O'Connell, 1988). The determination of the surface water quality impacts of this migration requires further study. The establishment of a regional wastewater treatment facility should be evaluated from an economic and capital facilities perspective.

Stormwater runoff results from an increase in impervious surface area associated with development of land. The presence of a high water table, thin soil layers, and permeable substrate promotes extensive surface-groundwater interaction and exchange. The effects of this exchange on the quality of Florida Bay waters have not been quantified. Impacts of stormwater runoff will only increase as the rapid population growth and development in the Keys continues (Monroe County Planning Department, 1986). Known land use activities within the Keys that are potential sources of toxic wastes are solid waste landfills and marinas. Marinas contribute pollutants from fuel spills, solvents used in boat construction and repairs, and heavy metals from bottom paints (Nixon *et al.*, 1973; Maloney *et al.*, 1980; U.S. Environmental Protection Agency, 1981, 1985; Olsen and Burd, 1982; Bell and Leeworthy, 1984). In addition, as indicated in **Table 82**, many marinas in the Keys have live-aboards, but no pump-out or sewage disposal facilities.

There is only one solid waste landfill operating in the study area, as indicated in **Table 86**. This facility is currently operating under a permit from the DER. There are no data as to the effects on the groundwater and surface water in the study area. Many studies have documented the typical constituents in, and impacts of leachate plumes in the groundwater (Russell, 1986). The location and composition of historic trash and solid waste disposal sites also is currently undetermined. The presence and status of hazardous material users and generators is currently undocumented. As is the case in most of Florida, the permeable surficial soils and high water table are extremely susceptible to contamination by improper disposal of hazardous materials.

IV. REFERENCES

Alexander, T.R. 1967. A tropical hammock on the Miami (Florida) Limestone - a twenty-five year study. *Ecology*, 48 (5):863-867.

Alexander, T.R. and A.G. Crook. 1984. Recent vegetational changes in South Florida. In: Gleason, P.J. (Ed), *Environments of South Florida: Present and Past II*. Miami Geological Society, Coral Gables, Florida, pp. 61-72.

Allen, R.P. 1958. A progress report on the wading bird surveys. Reports 1 and 2. Unpublished report, National Audubon Research Department, Tavernier, FL.

Allison, R.V. 1950. The importance of trace elements in Florida agriculture. *Soil Sci. Soc. Fl. Proc.*, 10:100-109.

Allison, R.V., O.C. Bryan and J.H. Hunter. 1927. The stimulation of plant response on raw peat soils of the Florida Everglades through the use of copper sulfate and other chemicals. Bulletin 190. University of Florida Agricultural Experiment Station, Belle Glade, FL.

Allison, R.V. and A.P. Dachnowski-Stokes. 1932. Physical and chemical studies upon important profiles of organic soils in the Florida Everglades. In: *Proceedings of the Second International Congress of Soil Science*. Leningrad, USSR, pp. 223-245.

Anderson, S.D. 1986. South Dade agricultural pilot study. Technical Memorandum, South Florida Water Management District, West Palm Beach, Florida.

Antoine, J.W. and J.L. Harding. 1963. Structure of the continental shelf, northeastern Gulf of Mexico. Technical Report 63-13T, Department of Oceanography, Texas A&M University, College Station, TX, 18 pp.

Ashton, R.E., Jr. and P.S. Ashton. 1981. *Handbook of Reptiles and Amphibians of Florida, Part I: The Snakes*. Miami: Windward Publishing Co., 176 pp.

Ault, J.W., III. 1988. Everglades and Francis S. Taylor Wildlife Management Area deer and hog annual report 1987. Florida Game and Freshwater Fish Commission, West Palm Beach, FL.

Austin, D.F. 1978. Exotic plants and their effects in Southeastern Florida. *Environmental Conditions*, 5(1):25-34.

Avery, G.N. and L.L. Loope. 1980. Endemic taxa in the Flora of south Florida. Everglades National Park, South Florida Research Center report T-558, Everglades National Park, Homestead, FL.

Avery, G.N. and L.L. Loope. 1983. Plants of Everglades National Park: A preliminary checklist of vascular plants. South Florida Research Center Report T-574. Everglades National Park, Homestead, FL.

Bader, R.G. and M.A. Roessler. 1972. An ecological study of South Biscayne Bay and Card Sound. Rosenstiel School of Marine and Atmospheric Sciences, Report to U.S. Atomic Energy Commission and Florida Power and Light Co., University of Miami, Miami, FL.

Baker, J. 1988. Survey of chlorinated pesticide residues in groundwater in rural areas of Dade County. Technical Report 88-5. Dade County, Department of Environmental Resources Management, Miami, FL.

Baldwin, M. and H.W. Hawker. 1915. Cumulose soils. U.S. Department of Agriculture, Bureau of Soils, *Soil Survey, Ft. Lauderdale Area*, pp. 31-52.

Bass, O.L., Jr. 1979. Colonial birds in south Florida national parks, 1977-1978. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL.

Bass, O.L., Jr. and J.A. Kushlan. 1982a. Status of the Cape Sable sparrow. South Florida Research Center Report T-672. Everglades National Park, Homestead, FL.

Bass, O.L., Jr. and J.A Kushlan. 1982b. Status of the osprey in Everglades National Park. Report Number M-679. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL.

Beard, D.B. 1938. Wildlife reconnaissance, Everglades National Park project. Report of the U.S. Department of the Interior, National Park Service, Washington, D.C.

Beardsley, G.L., Jr. 1967. Distribution in the water column of migrating juvenile pink shrimp, Penaeus duorarum (Burkenroad), in Buttonwood Canal, Everglades National Park, Florida. Ph.D dissertation, University of Miami, Coral Gables, FL.

Behler, J.L. 1978. Feasibility of the establishment of a captive-breeding population of the American crocodile. South Florida Research Center Report T-509. Everglades National Park, Homestead, FL, 94 pp.

Beissinger, S.R. and J.E. Takekawa. 1983. Habitat use by and dispersal of snail kites in Florida during drought conditions. *Florida Field Naturalist*, 11(3):89-106.

Belanger, T.V. and J.R. Platko, II. 1986. Dissolved oxygen budgets in the Everglades Water Conservation Area 2A. Florida Institute of Technology, Report to the South Florida Water Management District, West Palm Beach, FL.

Belanger, T.V., D.J. Scheidt and J.R. Platko II. 1989. Effects of nutrient enrichment on the Florida Everglades. *Lake and Reservoir Management, North American Lake Management Society*, 5(1):101-111.

Belden, R.C. 1988. The Florida panther. In: Chandler, W.J. (Ed.) *Audubon Wildlife Report 1988/1989*, National Audubon Society. New York: Academic Press, Inc., pp. 514-532.

Bell, F.W. and V.R. Leeworthy. 1984. Estimation of the demand and supply of marina services in the State of Florida. Report to the Bureau of State Lands Management, Florida Department of Natural Resources, Tallahassee, FL.

Bennetts, R.E., M.W. Collopy and S.R. Beissinger. 1988. Nesting ecology of snail kites in Water Conservation Area 3A. Tech. Report Number 31. Florida Cooperative Fish and Wildlife Research Unit, Department of Wildlife and Range Science, University of Florida, Gainesville, FL, 174 pp.

Berner, L. and M.L. Pescados. 1988. *The Mayflies of Florida.* University Presses of Florida: Gainesville, FL.

Bert, T.M. and J.M. Stevely. 1989 (abstract). Population characteristics of the stone crab, Menippe mercenaria, in Florida Bay and the Florida Keys. *Bull. Mar. Sci.* 44(1):515. Presented at: *Symposium on Florida Bay, a Subtropical Lagoon.* U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Bert, T.M., J. Tilmant, J. Dodrill and G.E. Davis. 1986. Aspects of the population dynamics and biology of the stone crab, Menippe mercenaria, in Everglades and Biscayne National Parks as determined by trapping. Report Number SFRC-86/04. South Florida Research Center, Everglades National Park, Homestead, FL.

Birnhak, B.I. and J.P. Crowder. 1974. An evaluation of the extent of vegetation habitat alteration in south Florida, 1943-1970. South Florida Environmental Project Report DI-SFEP-74-22. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, NTIS PB-231621, Atlanta, Ga.

Bjork, R., J.C. Ogden and G.V.N. Powell. 1987. Memorandum to Everglades National Park and South Florida Water Management District on the need for research in the C-111 Basin. National Audubon Society, Tavernier, Florida.

Blair, T.A. and R.C. Fite. 1965. *Weather Elements: a Text in Elementary Meteorology.* 5th ed., Englewood Cliffs, NJ: Prentice-Hall Inc.

Blum, L.K., A.L. Mills, J.C. Zieman and R.T. Zieman. 1988. Abundance of bacteria and fungi in seagrass and mangrove detritus. *Mar. Ecol. Prog. Ser.* 42(1):73-78.

Bolte, W. and O.L., Bass, Jr. 1980. Twenty-nine year synopsis of the Coot Bay Christmas bird count, Everglades National Park. Report Number T-605. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL, 19pp.

Bowman, R., G.V.N. Powell, J.A. Hovis, N.C. Kline and T. Wilmers. 1989. Variations in reproductive success between sub-populations of the osprey, (Pandion haliaetus), in south Florida. *Bull. Mar. Sci.,* 44(1):245-250.

Boyt, F.L., S.E. Bayley, and J. Zoltek Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. *Journal of the Water Pollution Control Federation.* May 1977:789-799.

Bradley, J.T. 1972. Climate of Florida. In: Climate of the States. Environmental Data Service, No. 60-8. Silver Springs, MD.

Brady, J.R. and D.S. Maehr. 1985. Distribution of black bears in Florida. *Florida Field Naturalist*, 13(1):1-24.

Briggs, J.C. 1958. A list of Florida fishes and their distribution. *Bulletin Florida State Museum of Biological Science*, 2(8):223-318.

Brock, T.D. 1970. Photosynthesis of algal epiphytes of Utricularia in Everglades National Park. *Bull. Mar. Sci.*, 20:952-956.

Browder, J. 1976. Water, wetlands, and wood storks in southwest Florida. Ph.D. Dissertation. University of Florida, Gainesville, FL.

Browder, J.A. 1981. Perspective on the ecological causes and effects of the variable algal composition of southern Everglades periphyton. South Florida Research Center Report T-643, National Park Service, Everglades National Park, Homestead, FL.

Browder, J.A. 1982. Biomass and primary production of microphytes and macrophytes in periphyton habitats of the southern Everglades. South Florida Research Center Report T-662, National Park Service, Everglades National Park, Homestead, FL.

Browder, J.A. 1985. Relationship between pink shrimp production on the Tortugas grounds and water flow patterns in the Florida Everglades. *Bull. Mar. Sci.*, 37(3):839-856.

Browder, J.A., S. Black, P. Schroeder, M. Brown, M. Newman, D. Cottrell, D. Black, R. Pope and P. Peck. 1981. Perspective on the ecological causes and effects of the variable algal composition of southern Everglades periphyton. South Florida Research Center Report T-643, National Park Service, Everglades National Park, Homestead, FL.

Browder, J.A., S. Black, and D. Black. 1982. Comparison of laboratory growth of Hyla squirella tadpoles on Everglades periphyton of three different taxonomic compositions. Report to Everglades National Park by Rosenstiel School of Marine and Atmospheric Sciences, Contract CX5280-8-1904, University of Miami, Miami, FL.

Brown, J.W. 1987. Studies of humic and fulvic acid dynamics in coastal marine waters of south Florida, USA. *Mar. Environ. Res.*, 21(3):163-174.

Cairns, J., Jr. and K.L. Dickson. 1971. A simple method for the biological assessment of the effects of waste discharges on aquatic bottom dwelling organisms. *Journal of Water Pollution Control Federation*, 43(5):755-772.

Cairns, J., Jr., Lanza G.R. and B.G. Parker. 1972. Pollution related structural and functional changes in aquatic communities with emphasis on freshwater algae and protozoa. *Proceedings of Academy of Natural Sciences of Philadelphia*, 124(5)79-127.

Carr, A., and C.J. Goin. 1955. *Guide to the Reptiles, Amphibians, and Freshwater Fishes of Florida*. University of Florida Press: Gainesville.

Carter, L.J. 1974. *The Florida Experience: Land and Water Policy in a Growth State.* John Hopkins University Press: Baltimore.

Carter, M.R., L.A. Burns, T.R. Cavinder, K.R. Dugger, P.L. Fore, D.B. Hicks, H.F. Revels and T.M. Schmidt. 1973. Ecosystems analysis of the Big Cypress Swamp and estuaries. Ecological Report Number DI-SFEP-74-51, U.S. Environmental Protection Agency, Athens, GA, 375 pp.

Casselman, T.W. and V.E. Green, Jr. 1971. Plastic lined mole drains in organic soils. *Soil and Crop Sci. Soc. of Fla. Proc.*, 31.

Causaras, C.R. 1985. Geology of the surficial aquifer system, Broward County, Florida. Report 84-4068 Water Resources Division, U.S. Geological Survey, Tallahassee, FL, 167 pp.

Center for Wetlands. 1979. Resource inventory and analysis of the Big Cypress National Preserve. Center for Wetlands, University of Florida, Gainesville, FL.

Center, T.D. and F.A. Dray, Jr. 1986. Melaleuca quinquenervia, a serious threat to south Florida's wetlands. U.S. Department of Agriculture Aquatic Plant Management Laboratory, Ft. Lauderdale, FL.

Central and Southern Florida Flood Control District. 1950. A report on water resources of Everglades National Park Florida. Central and South Florida Flood Control District, West Palm Beach, FL.

Central and Southern Florida Flood Control District. 1970. A report on water resources of Everglades National Park, Florida. Central and South Florida Flood Control District, West Palm Beach, FL.

Chamie, J.P.M. 1976. The effects of simulated sewage effluent upon decomposition, nutrient status and litter fall in a central Michigan peatland. Ph.D Dissertation. University of Michigan, Ann Arbor, MI.

Chinn Fatt, J. and J.D. Wang. 1987. Canal discharge impacts on Biscayne Bay salinities. Research/Resources Management Report SER-89, United States Department of the Interior, National Park Service, Southeast region, Atlanta, GA, 229 pp.

CH_2M Hill. 1978. Phase 2 water quality studies in the Everglades Agricultural Area in Florida. Florida Sugar Cane League, Clewiston, FL.

CH_2M Hill. 1979. Phase 3 water quality studies in the Everglades Agricultural Area of Florida. Florida Sugar Cane League, Clewiston, FL.

Clapp, R.B., R.C. Banks, D. Morgan-Jacobs and W.A. Hoffman. 1982a. Marine birds of the southeastern United States and Gulf of Mexico. Part I: Gaviiformes through Pelecaniformes. FWS/OBS-82/01, U.S.Fish and Wildlife Service, Washington, D.C.

Clapp, R.B., D. Morgan-Jacobs and R.C. Banks. 1982b. Marine birds of the southeastern United States and Gulf of Mexico. Part II: Anseriformes. FWS/OBS-82/20, U.S. Fish and Wildlife Service, Washington, D.C.

Clapp, R.B., D. Morgan-Jacobs and R.C. Banks. 1983. Marine birds of the southeastern United States and Gulf of Mexico. Part III: Charadriiformes. FWS/OBS-83/30, U.S. Fish and Wildlife Service, Washington, D.C.

Clark, S.H. 1971. Factors affecting the distribution of fishes in Whitewater Bay, *Florida Sea Grant Technical Bulletin*, Number. 8, Everglades National Park, Homestead, FL, 97 pp.

Clark, S.H. 1974. A study of variation in trawl data collected in Everglades National Park, Florida. *Trans. Am. Fish. Soc.*, 4:777-785.

Clayton, B.S. 1943. Nature and extent of the surface subsidence of the organic soils of the Everglades: I. Shrinkage and subsidence due to drainage and cultivation. *Proceedings of the Soil Science Society of Florida*, 5-A:118-120.

Clugston, J.P. 1966. Centrarchid spawning in the Florida Everglades. *Quarterly Journal Fl. Acad.Sciences*, 29:137-143.

Coale, F.J. 1987. Sugar cane. In: Izuno, F.T. and A.B. Bottcher (Eds.), *The effects of on-farm agricultural practices in the organic soils of the EAA on nitrogen and phosphorus transport: Phase II* (Draft report). Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Cohen, A.D. and T.D. Davies. 1989 (abstract). Petrographic/botanical composition and significance of the peat deposits of Florida Bay. *Bull. Mar. Sci.*, 44(1). Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Cohen, A.D. and W. Spackman. 1972. Methods in peat petrology and applications to reconstruction of paleoenvironments, *Geol. Soc. America Bull.*, 83(1):129-142.

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*, Abt. B 162:71-114.

Cohen, A.D. and W. Spackman, Jr. 1984. The petrology of peats from the Everglades and coastal swamps of southern Florida. In: Gleason, P.J. (Ed.) *Environments of south Florida, Present and Past.* Miami Geological Society, Coral Gables, FL, pp. 352-374.

Collins, L.A. and J.H. Finucane. 1984. Ichthyoplankton survey of the estuarine and inshore waters of the Florida Everglades, May 1971 to February 1972. National Oceanic and Atmospheric Administration, Miami, Florida, 75 pp.

Collopy, M. and P. Frederick. 1986. Wading bird nesting success and foraging dispersion in Water Conservation Area 3A and Everglades National Park-Interim Report. Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Conway, V.C. 1938. Studies on the autecology of Cladium mariscus R. Br. The growth of leaves. *New Phytologist*, 37:254-278.

Cooke, C.W. 1945. Geology of Florida. *Florida Geological Survey Bull.*, 29:1-339.

Cooper, R.M. 1989. An atlas of the Everglades Agricultural Area surface water management basins. Technical Memorandum. South Florida Water Management District, West Palm Beach, FL.

Cooper, R.M. 1990, (in press). An atlas of surface water management basins in the Everglades: the Water Conservation Areas and Everglades National Park. Draft technical report. South Florida Water Management District, West Palm Beach Fl.

Cooper, R.M. and J. Lane. 1987a. An atlas of eastern Dade County surface water management basins. Technical Memorandum, South Florida Water Management District, West Palm Beach, FL.

Cooper, R.M. and J. Lane. 1987b. An atlas of eastern Broward County surface water management basins. South Florida Water Management District, West Palm Beach, FL, 76 pp.

Cost, N.D. and G.C. Craver. 1981. Distribution of Melaleuca in South Florida, measured from the air. In: Geiger, R.K. (Ed.) *Proceedings of Melaleuca Symposium*, September 23-24, 1980. Florida Division of Forestry, Department of Agriculture and Consumer Services, Tallahassee, FL.

Costello, T.J., D.M. Allen and J.H. Hudson. 1986. Distribution, seasonal abundance and ecology of juvenile northern pink shrimp, Penaeus duorarum, in the Florida Bay area. Technical Memorandum Number NOAA-TM-NMFS-SEFC-161. National Marine Fisheries Service, 89 pp.

Cottrell, D.J. 1989 (abstract). Holocene evolution of the northeastern coast and islands of Florida Bay. *Bull. Mar. Sci.*, 44(1). Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science, 1-5 June 1987.

Cox, S.C., D. Lewis, S. McCollum, M. Bledsoe and R. Marrotte. 1988. Subsidence study of the Everglades Agricultural Area for the South Florida Water Management District. U.S. Department of Agriculture, Soil Conservation Service, Palm Beach Soil & Water Conservation District, Green Acres, FL, 25 pp.

Craighead, F.C., Sr. 1968. The role of the alligator in shaping plant communities and maintaining wildlife in the southern Everglades. *The Florida Naturalist,* 41:2-7;69-74.

Craighead, F.C., Sr. 1971. *The Trees of South Florida.* Volume 1. The natural environments and their succession. Coral Gables, FL.: University of Miami Press.

Craighead, F.C. and V.D. Gilbert. 1962. The effect of Hurricane Donna on the vegetation of southern Florida. *J. Fla. Acad. Sci.,* 25:1-28.

Crowder, J.P. 1974. The freshwater fishes and fisheries of south Florida. South Florida Environmental Project, Ecological Report Number DI-SFEP-74-26. U.S. Fish Wildlife Service, Atlanta, Ga.

Courtenay, W.R., Jr. and D.A. Hensley. 1979. Survey of introduced non-native fishes. Phase I report; Introduced exotic fishes in North America: Status 1979. Report submitted to National Fisheries Research Laboratory, U.S. Fish Wildlife Service, Gainesville, FL.

Custer, T.W. and R.G. Osborn. 1978. Feeding-site description of three Heron species near Beaufort, North Carolina. In: Sprunt IV, A., J.C. Ogden, and S. Winckler, (Eds). *Wading Birds*. National Audubon Society Research Report 7:355-360.

Dade County Department of Environmental Resources Management. 1980. East Everglades resources planning project. Proposed Management plan for the east Everglades. Department of Environmental Resources Management, South Florida Water Management District, Florida Department of Environmental Regulation and Everglades National Park, Homestead. Florida.

Dalrymple, G.H. (in press). Herpetofauna of Long Pine Key, Everglades National Park, with relation to vegetation, hydrology and fire. In: *The Management of Reptiles, Amphibians, and small Mammals in North America*. U.S. Department of Agriculture, U.S. Forest Service Symposium, Flagstaff, Arizona.

Davies, T.D. 1989. Palynology and stratigraphy of Florida Bay peats and the evolution of the Bay area. *Bull. Mar. Sci.*, 44(1).

Davis, C.C. and R.H. Williams. 1950. Brackish water plankton of mangrove areas in southern Florida. *Ecology*, 31(4):519-531.

Davis, G.E. and J.W. Dodrill. 1980. Marine parks and sanctuaries for spiny lobster fisheries management, In: *Proceedings of the Gulf and Caribbean Fisheries Institute*, 32nd Annual Session, pp. 194-207.

Davis, G.E. and C. Hilsenbeck. 1974. The effects of watershed management on the Shark Slough/Whitewater Bay Estuary of Everglades National Park, Florida. Unpublished manuscript, 16 pp.

Davis, G.E. and M.C. Whiting. 1977. Loggerhead sea turtle nesting in Everglades National Park, Florida, USA. *Herpetologia*, 33:18-28.

Davis, J.H. 1940. The ecology and geologic role of mangrove in Florida. Publication Number 517, *Papers from Tortugas Laboratory* 32:303-412, Carnegie Institute, Washington, D.C.

Davis, J.H., Jr. 1943a. The natural features of southern Florida, especially the vegetation, and the Everglades. Bulletin No. 25, Florida Geological Survey, Tallahassee, Florida.

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.

Davis, J.H., Jr. 1946. The peat deposits of Florida - their occurrence,development and uses. Bulletin 30:1-247, Florida Geological Survey, Tallahassee, FL.

Davis, R.O.E. and H.H. Bennett. 1927. Grouping of soils on the basis of mechanical analysis. Circular 419. U.S. Department of Agriculture.

Davis, S.M. 1981. Mineral flux in the Boney Marsh, Kissimmee River. Mineral retention in relation to overland Flow during the three year period following reflooding. Technical Publication 81-1, South Florida Water Management District, West Palm Beach, FL.

Davis, S.M. 1982. Patterns of radiophosphorus accumulation in the Everglades after its introduction into surface water. Technical Publication 82-2, South Florida Water Management District, West Palm Beach, FL, 28 pp.

Davis, S.M. 1984. Cattail leaf production, mortality, and nutrient Flux in Water Conservation Area 2A, Technical Publication 84-8. South Florida Water Management District, West Palm Beach, FL.

Davis, S.M. 1989. Sawgrass and cattail production in relation to nutrient supply in the Everglades. In: Sharitz, R.R. and J.W. Gibbons, (Eds). *Freshwater Wetlands and Wildlife*, Office of Scientific and Technical Information, U.S. Department of Energy, Oak Ridge, Tenn.

Davis, S.M. 1991. Sawgrass and cattail nutrient flux: Leaf turnover, decompositon, and nutrient flux of sawgrass and cattail in the Everglades. *Aquatic Botany*, 40:203-224.

Davis, S.M and L.A. Harris. 1978. Marsh plant production and phosphorus flux in Everglades Conservation Area 2: In: Drew, M. A. (Ed.) *Environmental quality through wetlands utilization*. Symposium Proceedings, Restoration of the Kissimmee River and Taylor Creek-Nubbin Slough Basin, Tallahassee, FL. Pp. 171-181.

Davis, S., L. Gunderson, R. Hofstetter, D. Swift and B. Waller. 1987. An assessment of the potential benefits to the vegetation and water resources of Everglades National Park and the southern Everglades ecosystem associated with the General Design Memorandum to improve water deliveries to Everglades National Park. Statement Paper. South Florida Research Center, Everglades National Park, Homestead, FL.

Defelice, D.R. and G.W. Lynts. 1978. Benthic marine diatom associations, upper Florida Bay, Florida, USA and associated sounds. *J. Phycol.*, 14(1):25-33.

Defelice, D.R. and G.W. Lynts. 1979. Biotic and abiotic parameters affecting diversity in modern and ancient benthic diatom assemblages of Florida. *Florida Scientist*, 42 (1, suppl.):44.

Defelice, D.R. and G.W. Lynts. 1980. Epiphytic diatoms as r selectors in Florida Bay, Florida. *Florida Scientist*, 43 (suppl. 1):23.

DeGrove, J.M. 1984. History of water management in south Florida. In: Gleason, P.J. (Ed.) *Environments of south Florida: Present and Past II*. Miami Geological Society, Coral Gables, FL, pp. 22-27.

Dade County Department of Environmental Resources Management. 1980. Proposed management plan for the East Everglades. DERM, Miami, FL.

Dade County Department of Environmental Resources Management. 1989. Agrichemical mixer-loader wells in Dade county, Florida: Potential for groundwater pollution. DERM, Miami, FL.

Day, F.P., Jr. 1982. Litter decomposition rates in the seasonally Flooded Great Dismal Swamp. *Ecology*, 63:670-678.

Diamond, C. 1989. Economic Impact Statement; Chapter 16C-52, Florida Administrative Code, as amended, the addition of Melaleuca quinquenervia to the Florida prohibited aquatic plant list. FAU-FIU Joint Center for Environmental and Urban Problems, Ft. Lauderdale, FL.

Dickson, K.G., A.C. Federico and J.R. Lutz. 1978. Water quality in the Everglades Agricultural Area and its impact on Lake Okeechobee. Technical Publication 78-3. South Florida Water Management District, West Palm Beach, FL, 132 pp.

Dineen, J.W. 1968. Determination of the effects of fluctuating water levels on the fish populations of Conservation Area 3. Florida Game & Fresh Water Fish Commission, West Palm Beach, FL.

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.

Dineen, J.W. 1974. Examination of water management alternatives in Conservation Area 2A. *In Depth Report* 2(3): 1-11, Central & Southern Florida Flood Control District, West Palm Beach, FL.

Dobkin, S. 1961. Early developmental stages of pink shrimp, Penaeus duorarum, from Florida waters. *Fish. Bull.* 61:321-349. U.S. Fish and Wildlife Service.

Dohrenwend, R.E. 1977. Evapotranspiration patterns in Florida. *Florida Scientist*, 40:184-192.

Dooley, J.K. and J.B. Higman. 1965. Studies of the fish stocks in the Everglades National Park--V, 1964-65. Annual report to National Park Service by the University Miami Institute of Marine Science, Miami, FL, 56 pp.

Douglas, M.S. 1947. *The Everglades: River of Grass.* Miami: Hurricane House, Inc. 406 pp.

Duellman, W.E. and A. Schwartz. 1958. Amphibians and reptiles of southern Florida. *Bulletin of the Florida State Museum, Biological Sciences,* 3:181-324. University of Florida, Gainesville, FL.

Duever, M.J., J.E. Carlson, J.F. Meeder, L.C. Duever, L.H. Gunderson, L.A. Riopelle, T.R. Alexander, R.F. Myers and D.P. Spangler. 1979. Resource investigation and analysis of the Big Cypress National Preserve. Final report to the U.S. Department of the Interior, National Park Service. National Audubon Society, Naples, FL.

Dunn, A.V. 1961. Required minimum discharges to Everglades National Park from Central and Southern Florida Flood Control District. Water Resources, National Park Service, Washington, D.C.

Dunson, W.A. 1980. Osmoregulation of crocodiles in Everglades National Park. Report Number T-599. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL, 29 pp.

Dunson, W.A. 1982. Salinity relations of crocodiles in Florida Bay USA. *Copeia,* 2:374-385.

Durako, M.J., J. A.Browder, W.L. Kruczynski, C.B. Subrakmanyam and R.E. Turner. 1985. Salt marsh habitat and fishery resources of Florida. In: Seaman Jr., W. (Ed.) *Florida Aquatic Habitat and Fishery Resources.* Special Symposium Publication of Florida Chapter of American Fisheries Society, Kissimmee, Florida, pp. 189-280.

Earle, J.E. and J.H. Hartwell. 1973. Hydrologic data for Taylor Slough. Open-file report Fl-73012, U.S. Geological Survey, Tallahassee, FL, 28 pp.

Echternacht, K.L. 1975. A study of the precipitation regimes of the Kissimmee River-Lake Okeechobee watershed. Technical Service Volume 1, Number 3. Florida Department of Environmental Regulation, Tallahassee, FL, 61 pp.

Egler, F.E. 1952. Southeast saline Everglades; vegetation of Florida and its management. *Vegetation,* 3:213-265.

Enos, P. and R.D. Perkins. 1979. Evolution of Florida Bay from island stratigraphy. *Geol. Soc. Am. Bull.,* 90 (1):59-83.

Evans, D.H. and T.M. Ellis. 1977. Sodium balance in the hatchling American crocodile, Crocodylus acutus. *Comp. Biochem. Physiol.,* 58 (A): 159-162.

Evink, G.L. 1981. Hydrological study in the area of Cross Key, Florida. Fl-ER 16-81. Bureau of Environment, Environmental Research, Department of Transportation, FL.

Everglades National Park. 1979. Mimeograph report of internal report from Everglades National Park to U.S. National Park Service. Homestead, FL.

Everglades National Park. 1989. An evaluation of habitat improvements and wildlife benefits from the U.S. Army Corps proposed Shark Slough GDM. U.S. National Park Service-South Florida Research Center response to COE GDM for Shark Slough. ENP, Homestead, FL.

Evermann, B.W., and W.C. Kendall. 1900. Check-list of the fishes of Florida. Report to the U.S. Fish Commission for 1899, pp. 35-103.

Ewald, J.J. 1965. The laboratory rearing of pink shrimp, Penaeus duorarum (Burkenroad). *Bull. Mar. Sci.,* 15 (2):436-449.

Ewel, J.R., R. Meador, R. Myers, L. Conde, and B. Edik. 1976. Studies of vegetation changes in south Florida. Department of Botany, University of Florida, Gainesville, FL.

Ewel, J.J., D.S. Ojima, D.A. Karl and W.F. DeBusk. August 1982. Schinus in successional ecosystems of Everglades National Park. South Florida Research Center Report T-676. Everglades National Park, Homestead, Florida.

Federico, A.C., K.G. Dickson, C.R. Kratzer and F.D. Davis. 1981. Lake Okeechobee water quality studies an eutrophication assessment. Technical Publication 81-2, South Florida Water Management District, West Palm Beach, FL.

Fernald, Edward A. and Donald J. Patton (eds.). 1984. *Water Resources Atlas of Florida*. Florida State University,Tallahassee, FL, 291 pp.

Fetter, C.W., Fr. 1980. *Applied Hydrogeology*. Columbus, Ohio: Charles E. Merrill Publishing Company.

Finucane, J.H. and A. Dragovich. 1959. Counts of red tide organisms, Gymnodinium breve and associated oceanographic data from Florida's west coast, 1954-1957. U.S. Fish and Wildlife Service. Special Science Report on Fisheries, 289:202-295.

Fish, J.E. 1988. Hydrogeology, aquifer characteristics and groundwater flow of the surficial aquifer system, Broward County, Florida. Water Resources Division Report 87-4034, U.S.Geological Survey, Tallahassee, FL, 92 pp.

Fiskell, J.G.A. and I.K. Nicholson. 1986. Organic phosphorus content of Pahokee muck and spodosols in Florida. *Soil and Crop Sci. Soc. Fla. Proc.*, 45:6-11.

Fleming, A.L., Esq. 1987. A study of the Florida aquatic plant control program with particular emphasis on inter-agency coordination and program management. Prepared for the South Florida Water Management District by Florida Atlantic University/Florida International University Joint Center for Environmental and Urban Problems, Ft. Lauderdale, FL.

Fleming, D.M. (in prep). American alligator distribution and abundance in relation to landscape and temporal characteristics of the Everglades. In: *Spatial and Temporal Patterns as Guidelines for Ecosystem Restoration*, Everglades Symposium Proceedings, Key Largo Fl. Oct. 22-27, 1989.

Fleming, D.M. , N.C. Kline and W.B.Robertson, Jr. 1989 (abstract). A comparison of osprey nesting distribution,abundance and success in Florida Bay from 1968 to 1984. *Bull. Mar. Sci.*, 44 (1):517. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Flora, M.D. and P.C. Rosendahl. 1981. Specific conductance and ionic characteristics of the Shark River Slough, Everglades National Park, Florida. South Florida Research Center Report T-615, Everglades National Park, Homestead, FL, 55 pp.

Flora, M.D. and P.C. Rosendahl. 1982. An analysis of surface water nutrient concentrations in the Shark River Slough, 1972-1980. South Florida Research Center Report T-653, Everglades National Park, Homestead, FL, 40 pp.

Flora, M.D., D.R. Walker, D.J. Scheidt, R.G. Rice and D.H. Landers. 1987. Response of experimental loading, Part 1: Nutrient uptake and periphyton production. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL.

Florida Commission on Rare and Endangered Animals. 1979. D.B. Ward (Ed.) *Rare and Endangered Biota of Florida, Volume 3, Plants*. University of Florida Press, Gainesville.

Florida Department of Environmental Regulation. 1989. Printout of permit files.

Florida Department of Health and Rehabilitative Services. 1989. Press release, March 6, 1989. (Public Health Advisory on mercury levels and the consumption of fish harvested from the WCAs), HRS, Tallahassee Fl.

Florida Department of Natural Resources. 1985. Florida Keys - Monroe County, Aquatic preserve management plan for proposed Florida Keys - Monroe County Aquatic Preserve. DNR, Tallahassee, FL, 190 pp.

Florida Department of Natural Resources. 1989. Annual report of the Conservation and Recreation Lands Program. DNR, Division of State Lands,Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1983. Everglades emergency deer hunt controversy. FGFWFC, Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1986. Statewide alligator management program proposal. FGFWFC, Gainesville, FL.

Florida Game and Fresh Water Fish Commission. 1989. Official lists of endangered and potentially endangered fauna and flora in Florida, compiled by D. Wood, FGFWFC, Tallahassee, FL.

Florida Sugar Cane League. 1988. Florida's Sugar Industry, 1987-88 Facts, Florida Sugar Cane League Inc., Clewiston, FL.

Fogarty, M.J. 1984. The ecology of the Everglades alligator. In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past II*. Miami Geological Society. Coral Gables, FL, pp. 211-218.

Forsee, W.T., Jr. 1940. Recent plant responses to some of the micro elements on Everglades peat. *Soil Sci. Soc. Fl. Proc.*, 2:53-58.

Forsee, W.T., Jr. and J.R. Neller. 1942. Phosphorus leaching studies in Everglades peat under lysimeter conditions. *Soil Sci. Soc. Fl. Proc*, 4:61-63.

Forthman, C.A. 1973. The effects of prescribed burning on sawgrass, Cladium jamaicense, in south Florida. Masters thesis, University of Miami, Coral Gables, FL.

Fowler, H.W. 1945. A study of the fishes of the southern piedmont and coastal plain. Monograph Number 7. Academy of Natural Sciences. Philadelphia, Pa.

Frederick, P.C. and M.W. Collopy. 1988. Reproductive ecology of wading birds in relation to water conditions in the Florida Everglades. Technical Report Number 30. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Fritts, T.H. and R.P. Reynolds. 1981. Pilot study of the marine mammals, birds and turtles in OCS areas of the Gulf of Mexico. FWS/OBS-81/36. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., 139 pp.

Gallatin, M.H. and J.R. Henderson. 1943. Progress report on the soil survey of the Everglades. *Soil Science Society of Florida Proceedings*, 5:95-104.

Gallatin, M.H., J.K. Ballard, C.B. Evans, H.S. Galberry, J.J. Hinton, J.P. Powell, E. Truett, W.L. Watts, G.C. Willson and R.G. Leighty. 1958. Soil Survey (Detail: Reconnaissance) of Dade Co., Florida. USDA Soil Conservation Service Series, 1947, No. 4.

Gandin, L.S. 1970. The planning of meterological station networks. In: *Distribution of Precipitation in Mountainous Areas, Vol. I. Proceeding of Geilo Symposium, Norway*. WMO Technical Note 111. World Meterological Organization, Geneva, 25 pp.

Gannon, P.T. 1978. Influence of Earth surface and cloud properties on south Florida sea breeze. Technical Report ERL 402-NHELM2. National Oceanic and Atmospheric Administration. Miami. Florida.

Gebelein, C.D. 1977. *Dynamics of recent carbonate sedimentation and ecology: Cape Sable, Florida.* Leiden, Netherlands:E.J. Brill, 244 pp.

Gentry, R.C. 1984. Hurricanes in south Florida. In: Gleason, P.J. (Ed.) *Environments of south Florida: Present and Past II.* Miami Geological Society. Coral Gables, Florida, pp. 73-81.

George, J.C. 1972. Everglades wildlife guide. Natural History Series. U.S. Department of the Interior, National Park Service, Homestead, Florida

Germain, G.J. and J.E. Shaw. 1988. Surface water quality monitoring network Technical Publication 88-3. South Florida Water Management District, West Palm Beach, FL.

Ghassemi, M., S. Quinlivan and M. Dellarco. 1982. Environmental effects of new herbicides for vegetation control in forestry. *Environment International*, 7:198-401.

Ginsburg, R.N. 1956. Environmental relationships of grain size and constituent particles in some south Florida carbonate sediments. *Am. Assoc. Petrol. Geol. Bull.*, 40(10):2384-2427.

Ginsburg, R.N. (ed.). 1964. *South Florida carbonate sediments.* Guidebook field trip No. 1. Geological Society of America Annual Meeting, 1964, Institute of Marine Sciences, University of Miami, Coral Gables, FL, 72 pp.

Ginsburg, R.N. and H.A. Lowenstam. 1958. The influence of marine bottom communities on the depositional environment of sediments. *J. Geol.*, 66:310-318.

Ginsburg, R.N., R. Rezak and J.L. Wray. 1972. *Geology of calcareous algae, notes for a short course. Sedimenta I.* The Comparative Sedimentology Laboratory, Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL.

Givens, L.S. 1956. Water level management - its effect on the ecology, wildlife and fisheries resources of Loxahatchee Refuge. Letter concerning Conservation Areas 1 and 2. A.R.M. Loxahatchee National Wildlife Refuge, Boynton Beach, FL.

Gleason, P.J. 1972. The origin, sedimentation, and stratigraphy of a calcite mud located in the southern freshwater Everglades. Ph.D. dissertation, Pennsylvania State University, University Park, Pennsylvania.

Gleason, P.J. (Ed.). 1974a. *Environments of south Florida:Present and Past.* Miami Geological Society, Miami, FL, 551 pp.

Gleason, P.J. 1974b. Chemical quality of water in Conservation Area 2A and associated canals, Central and Southern Florida Flood Control District, West Palm Beach, FL.

Gleason, P.J. and W. Spackman, Jr. 1974. Calcareous periphyton and water chemistry in the Everglades. In: Gleason, P.J. (Ed.). *Environments of South Florida, Present and Past.* Miami Geological Society, Miami, FL, pp. 146-181.

Gleason, P.J. and P.A. Stone. 1975. Prehistoric trophic levels status and possible cultural influences on the enrichment of Lake Okeechobee, (unpublished report). Central and Southern Florida Flood Control District, West Palm Beach, FL, p. 133.

Gleason, P.J., A.D. Cohen, P. Stone, W.G. Smith, H.K. Brooks, R. Goodrick and W. Spackman, Jr. 1984. The environmental significance of holocene sediments from the Everglades and saline tidal plains. In: Gleason, P.J. (Ed.). *Environments of south Florida, Present and Past II.* Miami Geological Society, Coral Gables, FL, pp. 297-351.

Gleason, P.J., P. Stone, D. Hallett and M. Rosen. 1974. Preliminary report on the effect of agricultural runoff on the periphytic algae of Conservation Area 1. Unpublished Report, Central and Southern Flood Control District, West Palm Beach, FL, 69 pp.

Goggin, J.M. and F. Sommer. 1949. Excavations on Upper Matecumbe Key, Florida. Yale University Publication Anthropology Number 41. Yale University Press.

Goode, R. 1985. *Everglades National Park/East Everglades resource planning and management implementation plan.* Everglades National Park/East Everglades Resource Planning and Management Committee.

Goodrick, R.L. 1984. The wet prairies of the northern Everglades. In: Gleason, P.J. (Ed.). *Environments of south Florida, Present and Past II.* Miami Geological Society, Coral Gables, FL, pp.185-189.

Goolsby, D.A., H.C. Mattraw, A.G. Lamonds, D.V. Maddy and J.R. Rollo. 1976. Analysis of historical water quality data and description of plan for a sampling network in central and southern Florida. Water Resources Investigations 76-52, U.S. Geological Survey, Tallahassee, FL, 124 pp.

Gorsline, D.S. 1963. Environments of carbonate deposition, Florida Bay and the Florida Straits. In: *Shelf carbonates of the Paradox Basin, a symposium.* Four Corners Geol. Soc., 4th field conference, Durango, Co., pp. 130-143.

Gunderson, L.H. 1989. Historical hydropatterns in wetland communities of Everglades National Park. In: Sharitz, R.R. and J.W. Gibbons (Eds.) *Fresh Water Wetlands and Wildlife.* Department of Energy Symposium Series Number 61, Savannah River Ecology Laboratory, Charleston, S.C. pp. 1099-1111.

Gunderson, L.H. and W.F. Loftus. 1989 (in press). The Everglades, competing land uses imperil the biotic communities of a vast wetland. In: W.H. Martin, S.C. Boyce, and A.C. Echternacht (Eds.). *Biotic communities of the southeastern United States.* New York: John Wiley and Sons.

Gunderson, L.H. and L.L. Loope. 1981. Plant communities of the Pinecrest area, Big Cypress National Preserve. South Florida Research Center Report T-666. Everglades National Park, Homestead, FL.

Gunderson, L.H., D.P. Brannon and G. Irish. 1986. Vegetation cover types of Shark River Slough, Everglades National Park derived from LANDSAT thematic mapper data. South Florida Research Center Report 86/03. Everglades National Park, Homestead, FL.

Gunderson, L.H., D. Taylor and J. Craig. 1983. Fire effects on Flowering and fruiting patterns of understory plants in pinelands of Everglades National Park. South Florida Research Center Report SFRC 83/04. Everglades National Park, Homestead, FL.

Gunderson, L.H., J.R. Stenberg and A.K. Herndon. 1988. Tolerance of five hardwood species to Flooding regimes in south Florida. In: D.J. Wilcox. (Ed.) *Interdisciplinary approaches to freshwater wetlands research.* Michigan State University Press, Ann Arbor, Michigan.

Haake, P.W. and J.M. Dean. 1983. Age and growth of four Everglades fishes using otoliths. South Florida Res. Center Technical Report 83/03. Everglades National Park-South Florida Research Center, Homestead, FL.

Hammar, E.H. 1929. The chemical composition of Florida Everglades peat soils with special reference to their inorganic constituents. *Soil Sci.*, Vol. 26:1-13.

Hand, J., V. Tauxe, and J. Watts. 1986. 1986 Florida Water Quality Assessment 305(b) Technical Report. Bureau of Water Quality Management. Florida Department of Environmental Regulation, Tallahassee, FL, 235 pp.

Hand, J., V. Tauxe, and J. Watts. 1987. 1987 Florida Water Quality Assessment 305(b) Technical Report. Bureau of Water Quality Management. Florida Department of Environmental Regulation, Tallahassee, FL.

Hand, J., V. Tauxe, and M. Friedemann. 1988. 1988 Florida Water Quality Assessment 305(b) Technical Report. Bureau of Surface Water Management. Florida Department of Environmental Regulation, Tallahassee, FL, 289 pp.

Hanna, A., and J. Hanna. 1948. *Lake Okeechobee: Wellspring of the Everglades.* Indianapolis: Bobbs-Merrill Co.

Harlem, P.W. 1979. Aerial photographic interpretation of the historical changes in Northern Biscayne Bay, Florida: 1925-1976. Sea Grant Technical Bulletin Number 40. University of Miami, Miami, FL.

Harper, R.M. 1927. *Natural resources of southern Florida, 18th Annual Report.* Florida Geological Survey, Tallahassee, FL.

Harrington, R.W., Jr. 1959. Delayed hatching in stranded eggs of marsh killifish, Fundulus confluentus. *Ecology*, 40:430-437.

Harshberger, J.W. 1914. *The vegetation of south Florida, south of 27 degrees 30 minutes north, exclusive of the Florida Keys.* Transactions Wagner Free Institute of Science: Philadelphia.

Hartwell, J.H., H. Klein, and B.F. Joyner. 1963. Preliminary evaluation of hydrologic situation in Everglades National Park, Florida. U.S Geological Survey, Miami, FL.

Hatton,, R.S., R.D. DeLaune and W.H. Patrick, Jr. 1983. Sedimentation, accretion and subsidence in marshes of Barataria Basin, Louisiana. *Limnology and Oceanography*, 28:494-502.

Heald, E.J. 1969. The production of organic detritus in a south Florida estuary. Ph.D. dissertation, University of Miami, Coral Gables, Florida, 111 pp.

Heald, E.J. 1970. The Everglades estuary: An example of seriously reduced inflow of freshwater. *Trans. Am. Fish. Soc.* 1:847-848.

Heald, E.J. 1971. The production of organic detritus in a south Florida estuary. Florida Sea Grant Technical Bulletin Number 6. University of Miami, Miami, FL, 110 pp.

Heald, E.J., W.E. Odum and D.C. Tabb. 1974. Mangroves in the estuarine food chain. In: Gleason, P.J. (Ed.) *Environments of south Florida: Present and Past.* Miami Geological Society. Miami, FL, pp. 182-189.

Healy, H.G. 1975. Potentiometric surface and areas of artesian Flow of the Florida aquifer in Florida. Florida Department of Natural Resources, Research Bureau of Geology Map Series 73.

Heilpren, A. 1887. *Explorations of the west coast of Florida and in the Okeechobee Wilderness.* Transactions Wagner Free Institute of Science: Philadelphia, Pennsylvania, 134 pp.

Hela, J. 1952. Remarks on the climate of south Florida. *Bull. Mar. Sci.* 2(2):438-447.

Henshall, J.A. 1891. Report upon the collection of fishes made in southern Florida during 1889. *Bulletin of U.S. Fisheries Commission*, 9:371-389.

Herndon, A.H. and J.R. Sternberg. 1987. Determinants of sawgrass distribution in hydric habitats (draft manuscript). South Florida Research Center, Everglades National Park, Homestead, FL, 23 pp.

Herndon, A.K. and D. Taylor. 1986. Response of a Muhlenbergia prairie to repeated burning: Changes in above-ground biomass. South Florida Research Center Report 86/05, Everglades National Park, Homestead, FL.

Herrnkind, W.F. and M.J. Butler, IV. 1986. Factors regulating post larval settlement and juvenile microhabitat use by spiny lobsters, Panulirus argus. *Mar. Ecol. Prog. Ser.* 34(1/2):23-30.

Higman, J.B. and M.A. Roessler. 1963. Studies of the fish stocks in the Everglades National Park (July 1962-June 1963)--V. Annual report to the Superintendent of Everglades National Park by the University Miami Marine Laboratory, Coral Gables, FL. Report Number ML 63597, 30 pp.

Higman, J.B. and K. Stewart. 1961. Studies on the fish stocks in the Everglades National Park (July 1959-June 1960)--II. Annual report to the Superintendent of Everglades National Park, Homestead, Florida by University Miami Marine Laboratory, Coral Gables, FL, 62 pp.

Higman, J.B. and B.J. Yokel. 1962a. Studies of the fish stocks in the Everglades National Park (July 1960-June 1961)--III. Annual report to Superintendent of Everglades National Park by the University Miami Institute of Marine Sciences, Coral Gables, FL, 41 pp.

Higman, J.B. and B.J. Yokel. 1962b. Studies of the fish stocks in the Everglades National Park (July 1961-June 1962)--IV. Annual report to Superintendent of Everglades National Park by the University Miami Institute of Marine Sciences, Coral Gables, FL.

Hilsenbeck, C.E., R.H. Hofstetter and T.R. Alexander. 1979. Preliminary synopsis of major plant communities in the East Everglades area, vegetation maps supplement. Department of Biology, University of Miami, Coral Gables, FL.

Hines, T.C., M.J. Fogarty and L.C. Chappell. 1968. Alligator research in Florida: a progress report. In: *Proceedings of Annual Conference of Southeast Association of Fish and Wildlife Agencies*, 22:166-180.

Hines, T.C and H.F. Percival. 1986. Alligator management and value-added conservation in Florida. In: *Proceedings of International Symposium*, New York Chapter-The Wildlife Society: Syracuse.

Hines, T.C and A.R. Woodward. 1980. Nuisance alligator control in Florida. *Wildlife Society Bulletin*, 8:234-241.

Hingtgen, T.M., R. Mulholland and R.W. Repenning. 1985b. Habitat suitability index models: white ibis. U.S. Fish and Wildlife Service Biology Report 82 (10.93), 18 pp.

Hoffman, W., R. Sawicki and G.T. Bancroft. 1989. Wading bird populations and distributions in the Water Conservation Areas of the Everglades: The 1987-1988 season, Ornithological Research Unit, National Audubon Society, report prepared for South Florida Water Management District, West Palm Beach, FL.

Hoffmeister, J.E. 1974. *Land from the Sea. The Geologic Story of South Florida.* University of Miami Press: Coral Gables, FL.

Hoffmeister, J.E., J.I. Jones, J.D. Milliman, D.R., Moore and H.G. Multer. 1964. Living and fossil reef types of south Florida: In: *A guide book for the Geological Society of America Convention; Field Trip No. 3.*

Hoffmeister, L.E., K.W. Stockman and H.G. Multer. 1967. Miami limestone of Florida and its recent Bahamian counterpart. *Geol. Soc. Amer. Bull.*, 78:175-190.

Hofstetter, R.H. 1976. Effects of fire in the ecosystem. Part I. Appendix K In: *South Florida Environmental Project.* University of Miami, Coral Gables, FL.

Hofstetter, R.H. 1990. University of Miami, Department of Biology, Miami, Florida. Personal communication. February 27, 1990.

Hofstetter, R.H. and C.E. Hilsenbeck. 1980. Vegetational studies of the East Everglades. Final Report to Metropolitan Dade County, Miami, Florida - East Everglades Resources Planning Project. Miami, FL, 109 pp.

Hofstetter, R.H. and F. Parsons. 1976. Effects of fire in the ecosystem. Part II. Appendix K In: *South Florida Environmental Project*, University of Miami, Coral Gables, FL.

Hofstetter, R.H. and F. Parsons. 1979. The ecology of sawgrass on the Everglades of southern Florida. In: Linn, M. (Ed.) *Proceedings of the First Conference on Scientific Research in the National Parks.* U.S. Department of the Interior, National Park Service Trans. and Proc., Series, No. 5. Washington, D.C.

Holden, M.W. 1964. Sea turtle nesting survey on Cape Sable Beach, Everglades National Park, Florida, 1964 season. Unpublished memorandum in File N4415. Everglades National Park, Homestead, FL.

Holden, M.W. 1965. Sea turtles nesting at Cape Sable. Unpublished memorandum in File N1415. Everglades National Park, Homestead, FL, 4 pp.

Hortenstein, C.C. and R.B. Forbes. 1972. Concentrations of nitrogen, phosphorus, potassium, and total soluble salts in soil solution samples from fertilized and unfertilized histosol. *J. Environ. Qual.*, 1(4):446.

Houde, E.D., S.A. Berkeley, J.J. Klinovsky and C.E. Dowd. 1976. Ichthyoplankton survey data report. Summary of egg and larval data used to determine abundance of clupeid fishes in the Eastern Gulf of Mexico. Sea Grant Technical Bulletin 32. University Miami, Miami, FL, 193 pp.

Houde, E.D. and N. Chitty. 1976. Seasonal abundance and distribution of zooplankton, fish eggs, and fish larvae in the eastern Gulf of Mexico, 1972 to 1974. Technical Report NMFS SSRF-701. National Oceanic and Atmospheric Administration, Miami, FL.

Houde, E.D., J.C. Leak, C.E. Dowd, S.A. Berkely and W.J. Richards. 1979. Ichthyoplankton abundance and diversity in the eastern Gulf of Mexico. Report to the U.S. Department of the Interior, Bureau of Land Management, Washington, D.C.

Howell, A.H. 1932. *Florida Bird Life.* New York: Coward-McCann, Inc.

Hudson, J.H., D.M. Allen and T.J. Costello. 1970. The flora and fauna of a basin in central Florida Bay. U.S. Fish and Wildlife Service Special Science Report Fish. 604:1-14.

Hulet, W.H. 1967. The role of calcium in the survival of marine teleosts in dilute seawater. *Bull. Mar. Sci.* 17:677-688.

Hunt, B.P. 1953. Food relationship between Florida spotted gar and other organisms in the Tamiami Canal. *Trans. Amer. Fish. Soc.*, 82:14-32.

Hunt, B.P. 1961. A preliminary survey of the physics-chemical characteristics of Taylor Slough with estimates of primary productivity. Report to Superintendent of Everglades National Park (mimeogr.), Homestead, FL.

Institute of Food and Agricultural Sciences. 1989. IFAS, University of Florida, Gainesville, FL.

Irvine, A.B., J.E. Caffin and H.I. Kochman. 1981. Aerial surveys for manatees and dolphins in western peninsular Florida: With notes on sightings of sea turtles and crocodiles. FWS/OBS-80/50. U.S. Fish and Wildlife Service, Washington, D.C.

Irving, T., 1969. *The conquest of Florida by Hernando De Soto.* New York: George P. Putnam & Son.

Irwin, G.A. and R.T. Kirkland. 1980. Chemical and physical characteristics of precipitation at selected sites in Florida. Water Resource Investigation 80-81, U.S. Geological Survey, Tallahassee, FL.

Izuno, F.T. 1987. Water management in the EAA. In: Izuno, F.T and A. B. Bottcher (Eds.). *The effects of on-farm agricultural practices in the organic soils of the EAA on the nitrogen and phosphorus transport: Phase II* (draft report). Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Izuno, F.T. and A.B. Bottcher, (Eds). 1987. *The effects of on-farm agricultural practices on the organic soils of the Everglades Agricultural Area on nitrogen and phosphorous transport: Phase II,* (draft report). Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Jacobsen, T. and J.A. Kushlan. 1986. Alligator nest Flooding in the southern Everglades: a methodology for management. University of Georgia, Athens, Ga., 26 pp.

Jannke, T.E. 1971. Abundance of young sciaenid fishes in Everglades National Park, Florida, in relation to season and other variables. Sea Grant Tech. Bull. Number 11. University Miami, Miami, FL, 128 pp.

Jarosewich, M. and J.I. Wagner. 1985. Geologic structure of the surficial aquifer system underlying Everglades National Park and the Big Cypress National Preserve. South Florida Research Center Report 85-02, Everglades National Park, Homestead, FL.

Jennings, M.L., A.R. Woodward and D.N. David. 1989. Florida nuisance alligator control program. In: *4th Eastern Wildlife Damage Control Conference*, Madison, WI.

Joanen, T. 1969. Nesting ecology of alligators in Louisiana. In: *Proceedings of Annual Conference Southeast Association of Fish and Wildlife Agencies*, 23:141-151.

Joanen, T. and L. McNease. 1972a. Population distribution of alligators with special reference to the Louisiana coastal marsh zones. Presented at a symposium of the American Alligator Council, Lake Charles, La., 12 pp. (Mimeogr.).

Joanen, T. and L. McNease. 1972b. A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. In: *Proceedings Annual Conference Southeast Association of Fish and Wildlife Agencies*, 26:252-275.

Joanen, T. and L. McNease. 1972c. 1971 coastal alligator census. Louisiana Wildlife and Fish Commission, New Orleans, La., 10 pp. (Mimeogr.).

Joanen, T., L. McNease and G. Perry. 1977. Effects of simulated Flooding on alligator eggs. In: *Proceedings Annual Conference of the Southeast Association of Fish and Wildlife Agencies*, 31:33-35.

Joanen, T. 1979. Time of egg deposition for the American alligator. In: *Proceedings Annual Conference of Southeast Association of Fish and Wildlife Agencies*, 33:15-19.

Johnson, J.M., I.C. Olmsted and O.L. Bass, Jr. 1983. Vegetation map of Long Pine Key, Everglades National Park. South Florida Research Center, Everglades National Park, Homestead, FL.

Johnson, L. 1958. A survey of the water resources of Everglades National Park, Florida, 46 pp.

Johnson, R.A., J.E. Wagner, D.J. Grigsby and V.A. Stern. 1988. Hydrologic effects of the 1984 through 1986 L-31 Canal drawdowns on the northern Taylor Slough Basin of the Everglades National Park. South Florida Research Center Report 88-01, Everglades National Park, Homestead, FL.

Jones, A.C., D.E. Dimitriou, J.J. Ewald and J.H. Tweedy. 1970. Distribution of early developmental stages of pink shrimp, Penaeus duorarum, in Florida waters. *Bull. Mar. Sci.*, 20(3):634-661.

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.

Joyner, B.F. 1973. Nitrogen, phosphorus, and trace metals in Florida surface waters, 1970-1971. Open-File Report Fl.-73028. U.S. Geological Survey, Tallahassee, FL, 30 pp.

Kadlec, R.H. 1989. Decomposition in wastewater wetlands. In: Hammer, D.A. (ed.), *Constructed Wetlands for Wastewater Treatment*. Lewis Press, Chelsea, Mi. :459-468.

Kahl, M.P. 1964. Food ecology of the wood stork (Mycteria americana). *Ecol. Monogr.*, 34:97-117.

Kale, H.W. II (ed.) 1978. *Birds. Vol. 2. Rare and Endangered Biota of Florida.* University Florida Press:Gainesville.

Kilby, J.D. and D.K. Caldwell. 1955. A list of fishes from the southern tip of the Florida peninsula. *Quart. J. Florida Acad. Sci.*, 18:195-206.

Klein, H. 1972. The shallow aquifer of southwest Florida. Open-File Rep. 72017. U.S. Geological Survey, Tallahassee Fl.

Klein, H., J.T. Armbruster, B.F. McPherson and H.J. Freiberger. 1975. Water and the south Florida environment. Water Resources Investigation 24-75. U.S. Geological Survey, Tallahassee, FL, 165 pp.

Klein, H. and J.E. Hull. 1978. Biscayne Aquifer, southeast Florida. Water resources Investigations. U.S. Geological Survey, Tallahassee, FL, pp.78-107.

Klopatek, J.M. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. In: Good, R.E., D.F. Whigham, and R.L. Simpson (Eds.). *Freshwater Wetlands, Ecological Processes and Management Potential.* New York: Academic Press, pp. 195-216.

Klukas, R.W. 1967. Factors affecting nesting success of loggerhead turtles at Cape Sable, Everglades National Park. Unpublished memorandum in File N1415. Everglades National Park, Homestead, FL, 58 pp.

Klukas, R.W. 1969. The Australian pine problem in Everglades National Park. Unpublished report in Everglades National Park Reference Library. South Florida Research Center, Everglades National Park, Homestead, FL.

Knapp, M., S. Burns and T. Sharp. 1986. Preliminary assessment of the groundwater resources of western Collier County, Florida. Technical Publication Number 86-1. South Florida Water Management District, West Palm Beach, FL.

Knecht, C.W. 1986. Elements of sugar cane production: water management. Notes from a short course presented by the Everglades Research and Education Center and the Palm Beach County Cooperative Extension Service, IFAS, University of Florida, Belle Glade, FL.

Kolipinski, M.C. 1969. Gar infested by Argulus in the Everglades. *Quart. J. Florida Acad. Sci.*, 32:39-49.

Kolipinski, M.C. and A.L. Higer. 1969. Some aspects of the effects of the quantity and quality of water on biological communities in Everglades National Park. Open File Report. 69007, U.S. Geological Survey, Tallahassee, FL.

Kreitman, A. and L. Wedderburn. 1984. Hydrogeology of south Florida. In: Gleason P.J. (Ed.). *Environments of South Florida: Present and Past II.* Miami Geological Society, Coral Gables, FL, pp. 405-426.

Kuchler, A.W. 1964. *Potential Natural Vegetation of the Conterminous United States.* New York: American Geographical Society.

Kushlan, J.A. 1974. Observations of the role of the American alligator, Alligator mississippiensis, in the southern Florida wetlands. *Copeia*, (4): 993-996.

Kushlan, J.A. 1975. Population changes of the apple snail (Pomacea paludosa) in the southern Everglades. *Nautilus*, 89:21-23.

Kushlan, J.A. 1976a. Wading bird predation in a seasonally fluctuating pond. *The Auk*, 93:464-476.

Kushlan, J.A. 1976b. Environmental stability and fish community diversity. *Ecology*, 57(4): 821-825.

Kushlan, J.A. 1977. Growth energetics of the white ibis. *The Condor*, 79:31-36.

Kushlan, J.A. 1978. Feeding ecology of wading birds. In: Sprunt Jr., A., J.C. Ogden, and S.A. Winkler, (Ed.). *Wading Birds*. National Audubon Society Research Report Number 7., New York, pp. 149-196.

Kushlan, J.A. 1979a. Feeding ecology and prey selection in the white ibis. *Condor*, 81:376-389.

Kushlan, J.A. 1979b. Prey choice by tactile-foraging wading birds. In: *Proceedings of the Colonial Waterbird Group*, 3:133-142.

Kushlan, J.A. 1980. Population Fluctuations of Everglades fishes. *Copeia*, 1980(4): 870-874.

Kushlan, J.A. 1986. Responses of wading birds to seasonally Fluctuating water levels: Strategies and their limits. *Colonial Waterbirds*, 9:155-162.

Kushlan, J.A. 1987. External threats and internal management: the hydrologic regulation of the Everglades, Florida, USA. *Environ. Manage.*, 11:109-119.

Kushlan, J.A. and P. Frohring. 1986. The history of the southern Florida wood stork population. *Wilson Bulletin*, 98:368-386.

Kushlan, J.A., and M.C. Kushlan. 1976. Everglades marsh--twenty-ninth winter bird-population study. *American Birds*, 30:1066-1067.

Kushlan, J.A. and M.C. Kushlan. 1977. Everglades marsh--fortieth breeding bird census. *American Birds*, 31:83.

Kushlan, J.A. and M.S. Kushlan. 1979. Observations on crayfish in the Everglades, Florida. *Crustaceana*, supplement 5, pp. 115-120.

Kushlan, J.A. and M.S. Kushlan. 1980a. Function of nest attendance in American alligator. *Herpetologica*, 36:27-32.

Kushlan, J.A. and M.S. Kushlan. 1980b. Everglades alligator nests: nesting sites for marsh reptiles. *Copeia*, 1980:930-932.

Kushlan, J.A. and M.S. Kushlan. 1980c. Population fluctuations of the prawn, Palemonetes paludosus, in the Everglades. *American Midland Naturalist*, 103(2):401-403.

Kushlan, J.A. and T.E. Lodge. 1974. Ecological and distributional notes on the freshwater fish of southern Florida. *Florida Scientist,* 37:110-128.

Kushlan, J.A. and D.A. White. 1977a. Nesting wading bird populations in southern Florida. *Florida Scientist,* 40 (1):65-72.

Kushlan, J.A. and D.A. White. 1977b. Laughing gull colonies in extreme southern Florida. *Florida Field Naturalist,* Vol. 5.

Kushlan, J.A., O.L. Bass, Jr. and L.C. McEwan. 1982a. Wintering waterfowl in the Everglades estuaries. *Am. Birds,* 36(5):815-819.

Kushlan, J.A., O.L. Bass, Jr. and L.C. McEwan. 1982b. Waterfowl in Everglades National Park. South Florida Research Center Report Number T-670. National Park Service, Everglades National Park, Homestead, FL, 26 pp.

Kushlan, J.A., M.C. Baumann and L.C. McEwan. 1978. A bibliography of south Florida wading birds. South Florida Research Center, Report Number T-514. National Park Service, Everglades National Park, Homestead, FL, 20 pp.

Kushlan, J.A., P.C. Frohring and D. Voorhees. 1984. History and status of wading birds in Everglades National Park. National Park Service Report, South Florida Research Center, Homestead, FL.

Kushlan, J.A., J.C. Ogden and A.L. Higer. 1975. Relation of water level and fish availability to wood stork reproduction in the southern Everglades, Florida. National Park Service, South Florida Research Center, Homestead, FL, 56 pp.

Kushlan, J.A., S.A. Voorhees, W.F. Loftus and P.C. Frohring. 1986. Length, mass and calorific relationships of Everglades animals. *Florida Scientist,* 49:65-79.

Lake Okeechobee Technical Advisory Council. 1987. Interim report to the Florida legislature, LOTAC, available from South Florida Water Management District, West Palm Beach, FL.

Lake Okeechobee Technical Advisory Council. 1988. Interim report to the Florida legislature, LOTAC-II, South Florida Water Management District, West Palm Beach, FL.

Lapointe, B.E. and J.D. O'Connell. 1988. The effects of on-site sewage disposal systems on nutrient relations of ground waters and near shore waters of the Florida Keys. Unpublished report to National Oceanic and Atmospheric Administration (Office of Coastal Zone Management), Florida Department of Environmental Regulation, Monroe County Planning Department, International Marine Research, Big Pine Key, FL, 64 pp.

LaRosa, A.M. and L. Gunderson. (in press). Alien plant management in Everglades National Park: An historical perspective. In: *Proceedings of Symposium on Alien Plant Management,* U.S. Park Service and U.S. Forest Service, 1986, Hawaii.

Layne, J.N. 1965. Observations on marine mammals in Florida waters. *Bulletin of Florida State Museum, Biological* Sciences, 9:131-181.

Layne, J.N., (Ed.). 1976. *Rare and endangered biota of Florida. Vol. 1. Mammals.* Florida Committee on Rare and Endangered Plants and Animals. Gainesville: University Presses of Florida.

Layne, J.N. 1984. The land mammals of south Florida. In: Gleason, P.J. (Ed.) *Environments of south Florida: Present and Past II.* Miami Geological Society, Coral Gables, FL, pp. 269-296.

Leach, S.D., H. Klein and E.R. Hampton. 1972. Hydrologic effects of water control and management of southeastern Florida. Florida Division of Geology Report, Investigation 60, U.S. Geological Survey, Tallahassee,Fl.

Leak, J.C. 1977. Distribution and abundance of Carangidae (Pisces, Perciformes) larvae in the eastern Gulf of Mexico, 1971-1974. M.S. thesis, University Miami, Coral Gables, FL, 83 pp.

Lee, T.N. 1975. Circulation and exchange processes in southeast Florida's coastal lagoons. Technical Report, TR75-3, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, FL, 71 pp.

Lee, T.N. and C. Rooth. 1972. Exchange processes in shallow estuaries. Sea Grant Special Bulletin No.4. University of Miami, Miami,Fl., 33 pp.

Leighty, R.G., M.H. Gallatin, J.L. Malcolm and F.B. Smith. 1965. Soil Associations of Dade County, Florida. Circular S-77A, Agriculture Experiment Station, University of Florida, Gainesville, FL.

Lewis, R.R., III, R.G. Gilmore, Jr., D.W. Crewz and W.E. Odum. 1985. Mangrove habitat and fishery resources of Florida. In: Seaman, Jr., W. (Ed.) Florida *Aquatic Habitat and Fishery Resources.* Special Symposium Publication of Florida Chapter of American Fisheries Society, Kissimmee, FL, pp. 281-336.

Lewis, W.M., Jr. 1970. Morphological adaptations of cyprinodontoids for inhabiting oxygen deficient waters. *Copeia,* 1970:319-326.

Ligas, F.J. 1960. The Everglades bullfrog, life history and management. Federal Aid Project W-39-R. Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Light, S.S., J.R. Wodraska and S. Joe. 1989. The southern Everglades - the evolution of water management. *National Forum,* Winter 1989, 4 pp.

Lin, S. 1982. Preliminary report on rainstorm of April 23-26, 1982. South Florida Water Management District, West Palm Beach, FL.

Lin, S. and J. Lane. 1982. Preliminary report on rainstorm of March 28-29, 1982. South Florida Water Management District, West Palm Beach, FL.

Lindall, W.N., J.R. Hall, W.A. Fable and L.A. Collins. 1973. A survey of fishes and commercial invertebrates of the nearshore and estuarine zone between Cape Romano and Cape Sable, Florida. Ecological Report Number SFEP-74-44. South Florida Environmental Project, Gulf Coastal Fisheries Center. National Marine Fisheries Service, Panama City, FL, 66 pp.

Lloyd, R.M. 1964. Variations in the oxygen and carbon isotope ratios of Florida Bay mollusks and their environmental significance. *J. Geol.*, 72(1):84-111.

Loftus, W.F. 1986 (in press). Distribution and ecology of exotic fishes in Everglades National Park. In: *Proceedings Fourth Triennial Conference on Science in the National Parks.* Fort Collins, CO.

Loftus, W.F. 1987. Possible establishment of the mayan chichlid, Cichlosoma urophthalmus (Gunther) (Pisces:Cichlidae), in Everglades National Park, Florida. *Florida Scientist*, 50:1-6.

Loftus, W.F. 1988. Fishes of the Everglades marsh: responses to a seasonally variable environment. In: Dalrymple, G.H., W.F. Loftus and F.S. Bernardino, Jr. (Eds.). *Wildlife in the Everglades and Latin American wetlands.* Abstracted proceedings of the Winter 1985 conference, Miami, FL, pp. 3-4.

Loftus, W. 1989. Project data files from aquatic food web study. Everglades National Park-South Florida Research Center, Homestead, FL.

Loftus, W.F In press. Inventory of fishes of Everglades National Park. In: *Vertebrates of Everglades National Park.* National Park Service, SE Regional Technical Report.

Loftus, W.F. and J.A. Kushlan. 1987. Freshwater fishes of southern Florida. *Bulletin of Florida State Museum, Biological Sciences*, 31:146-343.

Loftus, W.F., J.D. Chapman and R. Conrow. (in press). Hydroperiod effects on Everglades marsh food webs with relation to marsh restoration efforts. In: *Proceedings Fourth Triennial Conference on Science in the National Parks.* Fort Collins, CO., July 1986.

Long, R.W. and O. Lakela. 1971. *Flora of Tropical Florida.* Miami: Banyan Books.

Loope, L.L. 1980. A bibliography of south Florida botany. South Florida Research Center Report T-550. Everglades National Park, Homestead, FL.

Loope, L.L. and G.N. Avery. 1979. A preliminary report on rare plant species in the flora of National Park Service areas of southern Florida. South Florida Research Center Report M-548, Everglades National Park, Homestead, FL.

Loope, L.L. and V.L. Dunevitz. 1981. Impact of fire exclusion and invasion of Schinus terebinthifolius on limestone rockland pine forests of southeastern Florida. South Florida Research Center Report T-645, Everglades National Park, Homestead, FL.

Loope, L.L. and N. Urban. 1980. A survey of fire history and impact in tropical hardwood hammocks in the East Everglades and adjacent portions of Everglades National Park. South Florida Research Center Report T-592, Everglades National Park, Homestead, FL.

Loope, L.L., D.W. Black, S. Black, G.N. Avery. 1979. Distribution and abundance of flora in limestone rockland pine forests of southeastern Florida. South Florida Research Center Report T-547. Everglades National Park, Homestead, FL.

Loveless, C.M. 1959. A study of the vegetation of the Florida Everglades. *Ecology,* 40:1-9.

Loveless, C.M., G.W. Cornwell, R.L. Downing, A.R. Marshall and J.N. Layne. 1970. Everglades water and its ecological implications. Report of the Special Study Team on the Florida Everglades. Central & Southern Florida Flood Control District, West Palm Beach, FL.

Loxahatchee National Wildlife Refuge. 1988. Melaleuca control plan (draft report). Loxahatchee Wildlife Refuge, Boynton Beach, FL.

Lucas, R.E. 1980. Mobility of phosphorus and potassium in Everglades histosols. In: *Proceedings of the 6th International Peat Congress*, Duluth, Minn., pp. 413-417.

Lugo, A.E. and S.C. Snedaker. 1974. The ecology of mangroves. *Annu. Rev. Ecol. Syst.*, Vol. 5, pp. 39-64.

Lutz, J.R. 1977a. Water quality characteristics of several southeast Florida canals. Technical Publication 77-4. South Florida Water Management District, West Palm Beach, Florida., 83 pp.

Lutz, J.R. 1977b. Water quality and nutrient loadings of the major inflows from the Everglades Agricultural Area to the Conservation Areas, southeast Florida. Technical Publication 77-6. South Florida Water Management District, West Palm Beach, FL, 40 pp.

Lutz, P.L. and A. Dunbar-Cooper. 1982. The nest environment of the American crocodile, Crocodylus acutus. South Florida Research Center, Report Number T-671. National Park Service, Everglades National Park, Homestead, FL, 38 pp.

Lutz, P.L. and A. Dunbar-Cooper. 1984. The nest environment of the American crocodile, Crocodylus acutus. *Copeia*,1:153-161.

Lyons, W.G., D.G. Barber, S.M. Foster, F.S. Kennedy, Jr. and G.R. Milano. 1981. The spiny lobster, Panulirus argus, in the middle and upper Florida Keys: population structure, seasonal dynamics, and reproduction. Florida. Marine Research Publication No. FMRP-38. Florida. Department of Natural Resources, Marine Research Laboratory, St. Petersburg, FL.

McCollum, S.H. and O.E. Cruz, Sr. 1981. Soil survey of Martin County area, Florida. U.S. Department of Agriculture, Soil Conservation Service.

McCollum, S.H., O.E. Cruz, L.T. Stem, W.H. Whittstruck, R.D. Ford, and F.C. Watts. 1978. Soil Survey of Palm Beach County Florida. USDA, SCS, in cooperation with University of Florida. Agricultural Experiment Station.

McCorquodale, D.S. 1986. An assessment of indicator bacteria and bacteriophages in surface waters of Biscayne Bay. Phase I Report. Department of Environmental and Resource Management, Dade County, Miami, FL.

McCoy, H.J. 1962. Ground water resources of Collier County, Florida, Survey Report Investigation Number 31. U.S. Geological Survey, Tallahassee, FL.

McCoy, H.J. 1972. Hydrology of western Collier County, Florida. Bureau of Geology Report Number 63. U.S. Geological Survey, Tallahassee, FL.

McDiarmid, R.W. and P.C.H. Pritchard. 1978. *Amphibians and Reptiles: Rare and Endangered Biota of Florida, Vol. 3.* Florida Game and Freshwater Fish Commission, Gainesville: University of Florida Press.

McDowell, L.L., T.C. Stephens and E.H. Steward. 1969. Radiocarbon chronology of the Florida Everglades peat. *Soil Sci. Soc. Am. Proc.*, 33:743-745.

MacGill, R.A., S.E. Gatewood, C. Hutchinson and D.D. Walker. 1976. Final report on the special project to prevent eutrophication of Lake Okeechobee. DSP-BCP-36-76, Florida Department of State Planning, Tallahassee, FL.

McKenzie, D.J. 1988. Water resources evaluation of the freshwater lens on Key West, Florida. Unpublished report. U.S. Geological Survey, Miami, FL.

McKenzie, D.J. and G.A. Irwin. 1988. Effects of two stormwater management methods on the quality of water in the Upper Biscayne Aquifer at two commercial areas in Dade County, Florida. Water Resources Investigation Report Number 88-4069. U.S. Geological Survey, Tallahassee, FL, 22 pp.

McPherson, B.F. 1970. Hydrobiological characteristics of Shark River Estuary, Everglades National Park, Florida. Open File Report Number 71002. Water Resources Division, U.S. Geological Survey, Tallahassee, FL, 113 pp.

McPherson, B.F. 1971. Water quality at the Dade-Collier training and transition Airport, Miami International Airport and Cottonmouth Camp-Everglades National Park, Florida, November 1969. U.S.G.S. Open File Report FL 70011. Tallahassee, FL.

McPherson, B.F. 1973. Water quality in the conservation areas of the Central and Southern Florida Flood Control District, 1970-72. Open-File Report 73014. U.S. Geological Survey, Tallahassee, FL.

McPherson, B.F., G.Y. Hendrix, H. Klein and H.M. Tysus. 1976. The environment of south Florida: a summary report. U.S. Geological Survey Professional Paper 1011.

McVey, J.P. and T. Wibbels. 1984. The growth and movements of captive reared Kemp's ridley sea turtles (Lepidochelys kempi) following their release in the Gulf of Mexico. National Oceanic and Atmospheric Administration Technical Memorandum, NMFS-SEFC-145, 25 pp.

MacVicar, T.K. 1983. Rainfall averages and selected extremes for central and south Florida. Technical Publication 83-2, South Florida Water Management District, West Palm Beach, Florida, 31 pp.

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.

MacVicar, T.K. 1988. Interim recommendations for C-111 basin. Memorandum to John Wodraska, Executive Director, South Florida Water Management District, West Palm Beach, FL.

MacVicar, T.K. and S.S.T. Lin. 1984. Historical rainfall activity in central and southern Florida: Average, return period estimates and selected extremes. In: Gleason, P.J. (Ed.) *Environments of south Florida: Present and Past.* Miami Geological Society, Coral Gables, FL, pp. 477-509.

MacVicar, T.K. and T. VanLent. 1984. Evaluation report. A thirty day field experiment of water deliveries to Northeast Shark River Slough, April - May, 1984. South Florida Water Management District,West Palm Beach, FL.

Maloney, F.E., B.D. Carter and R.G. Hamann. 1980. Legal aspects of recreational marina siting in Florida. Report to the U.S. Department of Commerce, Office of Sea Grants. Florida Sea Grant College Rep. No. 36. 69 pp.

Marshall, A.R. 1958. A survey of the snook fishery of Florida, with studies of the biology of the principal species, Centropomus undecimalis (Bloch). *Technical Series, Florida Board of Conservation*, 22:1-37.

Marx, J.M., and W.F. Herrnkind. 1986. Settlement of spiny lobster, Panulirus argus, in south Florida: an evaluation from two perspectives. *Can. J. Fish. Aquatic Sci.*, 43(1):2221-2227.

Mattraw, H.C., Jr., D.J. Scheidt and A.C. Federico. 1987. Analysis of trends in water quality data for Water Conservation Area 3A, the Everglades, Florida. Water Resources Investigations 87-4142. Prepared in cooperation with the National Park Service and South Florida Water Management District, U.S. Geological Survey, Tallahassee, FL.

Mattraw, H.C., Jr., B.C. Waller and B.F. McPherson. 1973. Effects of backpumping on water quality and biota in the Conservation Areas--nutrient uptake; U.S. Geological Survey, Miami, FL.

Mazzotti, F.J., J.A. Kushlan and A. Dunbar-Cooper. 1988. Desiccation and cryptic nest Flooding as probable causes of egg mortality in the American crocodile, Crocodylus acutus, in Everglades National Park, Florida. *Florida Scientist,* 51:65-71.

Mazzotti, F.J., W. Ostrenko and A.T. Smith. 1981. Effects of the exotic plants, Melaleuca quinquenervia and Casuarina equisetifolia, on small mammal populations in the eastern Florida Everglades. *Florida Scientist,* 44(2):65-71.

Meador, R.F. 1977. The role of mycorrhiza in influencing succession on abandoned Everglades farmland. Masters thesis, University of Florida, Gainesville, FL, 99 pp.

Meeder, J.F. and L.B. Meeder. 1989 (abstract). Hurricanes in Florida Bay: a dominant physical process. *Bull. Mar. Sci.* 44(1):518. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Melaleuca Task Force. 1990. Melaleuca management plan for South Florida. Recommendations from the Melaleuca Task Force. South Florida Water Management District, West Palm Beach, Florida.

Metro-Dade Planning Department. 1978. Residential land use. Conducted as part of the East Everglades Resources Planning Project. November 1978.

Metro-Dade Planning Department. 1979. Recreation land use. Conducted as part of the East Everglades Resources Planning Project. March 1979.

Metro-Dade Planning Department. 1988. Proposed land use element (support components), Metro-Dade County Comprehensive Development Master Plan for 2000 and 2010.

Merriam, D.F. 1989 (abstract). Overview of the geology of Florida Bay, review of recent developments. *Bull. Mar. Sci.* 44(1):519. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Merriam, D.F., C.E. Sorensen and R.V. Jenkins. 1987. Modern carbonate sediments in Shell Key Basin, Florida Bay. In: *Symposium on South Florida Geology.* Miami Geological Society Memo Number 3. Miami, FL, pp. 73-90.

Merriam, D.F., S. Sengupta and C.E. Sorensen. 1989 (abstract). Definition and implications of the subenvironments of Florida Bay. *Bull. Mar. Sci.* 44(1): 520-521. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Merriam, D.F., J.M. Fuhr, R.V. Jenkins and P.J. Zimmerman. 1989 (abstract). Pleistocene bedrock geology of Florida Bay, the Keys and the Everglades. *Bull. Mar. Sci.* 44(1):519-520. Abstract presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Millar, P. 1981. Water quality analysis in the Water Conservation Areas 1978-1979. Technical Memorandum. South Florida Water Management District, West Palm Beach, FL.

Miller, W.L. 1975. Nutrient concentrations of surface water in southern Florida September 1970 to April 1975. U.S.G.S. Open File Report FL 75010, Tallahassee, FL.

Miller, W.L. 1988. Description and evaluation of the effects of urban and agricultural development on the surficial aquifer system, Palm Beach County, FL. Water Resources Investigation Report Number 88-4056. U.S. Geological Survey, Tallahassee, FL, 58 pp.

Milleson, J.F. 1980. Chlorinated hydrocarbon pesticide residues in freshwater fishes within the South Florida Water Management District. Technical Memorandum, South Florida Water Management District, West Palm Beach, FL, 26 pp.

Mierau, R. 1974. Supplemental water use in the Everglades Agricultural Area. Technical Publication 74-4, Central & Southern Florida Flood Control District, West Palm Beach, FL, 46 pp.

Missimer, T.M. 1974. The geology of south Florida: a summary. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past II*. Miami Geological Society, Miami, Florida.

Molnar, G. and Bernardino, F. 1988. The potential impact of the proposed Dade County west wellfield on the vegetational communities of northeast Shark River Slough. A report prepared for the Dade County West Wellfield Technical Advisory Committee. Dade County Department of Environmental Resources Management (DERM), Miami, FL.

Monroe County Planning Department. 1986. Florida Keys Comprehensive Plan, Vol.1-3. Monroe County Planning Department, Key West, FL.

Montague, C.L., R.D. Bartleson, J.F. Gottgens, J.A. Ley and R.M. Ruble. 1989 (abstract). The distribution and dynamics of submerged vegetation along gradients of salinity in northeast Florida Bay. *Bull. Mar. Sci.* 44:(1):521. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Moore, J.C. 1953. The crocodile in the Everglades National Park. *Copeia*. 1:54-59.

Morello, F., S. Marshal and J. Fury. 1988. Fish Management Annual Progress Report, 1987-1988, Everglades region, Florida. Game and Freshwater Fish Commission, West Palm Beach, FL.

Morris, T. 1975. Everglades agricultural area backpumping study in water quality models for understanding potential eutrophication in Lake Okeechobee, Florida. F.G. Nordie and T. Gayle (Eds.) Center for Wetlands, University of Florida, Gainesville.

Morrison, D. 1980. The ecology of Batophora oerstedi (Chlorophyceae: Dasycladales): Productivity and seasonal periodicity. *Florida Scientist*, 43 (supplement 1):14.

Morrison, D. 1984. Seasonality of Batophora oerstedi (Chlorophyta), a tropical macro alga. *Mar. Ecol. Prog. Ser.* 14(2-3):235-244.

Morton, J.A. 1975. Cattails (Typha spp.)-Weed problem or potential crop? *Economic Botany*, 29:7-29.

Mulkey, D. and R. Clouser. 1988. The economic impact of the Florida sugar industry, Food and Res. Economics Department, IFAS, University of Florida, Gainesville, FL, p. 17.

Mytinger, L. and G.B. Williamson. 1987. Invasion of Schinus into saline communities of Everglades National Park. *Florida Scientist*, 50 (1):7-12.

National Park Service. 1979. Fire management plan for Everglades National Park, internal report from Everglades National Park to the National Park Service (mimeograph).

National Research Council. 1987. *Responding to Changes in Sea Level Engineering Implications.* Washington, D.C.: National Academy Press.

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.

Nesbitt, S.A., J.C. Ogden, H.W. Kale II, B.W. Patty and L.A. Rowse. 1982. Florida atlas of breeding sites for herons and their allies: 1976-78. FWS/OBS-81/49. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Nesbitt, S.F., R.R. Roth and W.B. Robertson, Jr. 1975. The status of the bald eagle in Florida 1972-1975. In: *Proceedings 29th Annual Conference S. E. Association Game and Fish Commission*, pp. 424-428.

Nickelsen, G.E. 1977. Marine epiphytes on Rhizophora mangle L. prop roots in Lake Surprise, Monroe County Planning Department, FL, 110 pp.

Nichols, D.S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. *Journal of the Water Pollution Control Federation*, 55:495-505.

Nicholson, I.K. and J.G.A. Fiskell. 1985. Extraction of inorganic P from Pahokee muck under various long-term field managements. *Soil and Crop Sci. Soc. Fla. Proc., 44:102-106.*

Nicholson, I.K. 1983. Partitioning of phosphorus in a Florida histosol. Dissertation. Abstract. 4/07-B: 2035.

Nixon, S.W., C.A. Oviatt and S.L. Northby. 1973. Ecology of small boat marinas. Marine Technical Report Number 5. University Rhode Island, Kingston, R.I., 20 pp.

Odell, D.K. 1975. Status and aspects of the life history of the bottlenose dolphin, Tursiops truncatus, in Florida. *J. Fish. Res. Bd. Can.*, 32:1,055-1,058.

Odum, H.T. and C.M. Hoskin. 1958. Comparative studies on the metabolism of marine waters. Texas University Institute of Marine Science Publication 5, pp. 16-46.

Odum, W.E. 1970. Utilization of the direct grazing and plant detritus food chains by the striped mullet, Mugil cephalus. In: *Marine food chains, a Symposium*, University of California Press, pp. 222-240.

Odum, W.E. 1971. Pathways of energy Flow in a south Florida estuary. Sea Grant Technical Bulletin Number 7, University of Miami, Miami, FL, 175 pp.

Odum, W.E. and E.J. Heald. 1972. Trophic analyses of an estuarine mangrove community. *Bulletin of Marine Science*, 22:671-738.

Odum, W.E., C.C. McIvor and T.J. Smith, III. 1982. The ecology of the mangroves of south Florida: a community profile. FWS/OBS-81/24. Reprinted September 1985. U.S. Fish and Wildlife Service

Odum, W.E., J.T. Smith III, J.K. Hoover and C.C. McIvor. 1984. *The ecology of tidal freshwater marshes of the United States east coast: A community profile.* FWS/OBS-83/17. U.S. Fish and Wildlife Service.

Ogden, J.C. 1975. Effects of bald eagle territoriality on nesting ospreys. *Wilson Bull.*, 87(4):496-505.

Ogden, J. 1978. Freshwater marshlands and wading birds in south Florida. In: Kale H. (ed.), *Rare and Endangered Biota of Florida, Vol. 2. Birds.* Gainesville, FL.: University Presses of Florida.

Ogden, J.C. 1978a. American crocodile. In: McDiarmid, R. (Ed.). *Rare and Endangered Biota of Florida, Vol. 3. Amphibians and Reptiles.* Gainesville:University Presses of Florida, 74 pp.

Ogden, J.C. 1978b. Status and nesting biology of the American crocodile, Crocodylus acutus (Reptilia, Crocodylidae) in Florida. *Journal of Herpetology* 12(2):183-196.

Ogden, J.C. 1988. Impacts of the Everglades GDM on populations of nesting wading birds in Everglades National Park. Unpublished memorandum. National Park Service, Everglades National Park, Homestead, FL.

Ogden, J.C. and R. Johnson. 1989. Long range environmental protection and restoration of the C-111 Basin and southeast coast estuaries. Unpublished memorandum. National Park Service, Everglades National Park, Homestead, FL.

Ogden, J.C., H.W. Kale, II and S.A. Nesbitt. 1980. The influence of annual variation in rainfall and water levels on nesting by Florida populations of wading birds. *Transactions of Linnaean Society of New York*, 9:115-126.

Ogden, J.C., J.A. Kushlan and J.T. Tilmant. 1976. Prey selectivity by the wood stork.*Condor*, 78:324-330.

Ogden, J.C., J.A. Kushlan and J.T. Tilmant. 1978. The food habits and nesting success of wood storks in Everglades National Park. Natural Resources Report No. 16. National Park Service, Everglades National Park, Homestead,Fl.

Ogden, J.C., W.F. Loftus and W.B. Robertson, Jr. 1987. Wood storks, wading birds and freshwater fishes. Statement paper. U.S. Army Corps of Engineers, General Design Memorandum on modified water deliveries to Everglades National Park, South Florida Research Center, Everglades National Park, Homestead, FL.

Ogden, J.C., D.A. McCrimmon, G.T. Bancroft and B.W. Patty. 1987a. Breeding populations of the wood stork in the southeastern U.S. *Condor*, 89:752-759.

Ogden, J.C. and B.W. Patty. 1982. The recent status of the wood stork in Florida and Georgia. In: Odum R. and J. Guthrie, (Eds.). *Proceedings Non-game and Endangered Wildlife Symposium*. Technical Bulletin WL5. Georgia Department Natural Resources, pp. 87-103.

Ogden, J.C., W.B. Robertson, G.E. Davis and T.W.Schmidt. 1974. Pesticides, polychlorinated biphenyls and heavy metals in upper food chain levels, Everglades National Park and vicinity. Report Number DI-SFEP-74-16. U.S. Department of Commerce, National Technical Information Service, Springfield, Va., 27 pp.

Olmsted, I.C. and L.L. Loope. 1981. Vegetation along a microtopographic gradient in the estuarine zone of Everglades National Park. South Florida Research Center, Everglades National Park, Homestead, FL.

Olmsted, I.C. and L.L. Loope. 1984. Plant communities of Everglades National Park. In: Gleason, P.J. (Ed.). *Environments of south Florida: Present and Past II*. Miami Geological Society, Coral Gables, Florida, pp. 167-184.

Olmsted, I.C., V.L. Dunevitz and J.M. Johnson. 1982. Vegetation map of Shark River Slough Everglades National Park. U.S. National Park Service. Homestead, Florida.

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.

Olmsted, I.C., L.L. Loope and R.P. Russell. 1981. Vegetation of the southern coastal region of Everglades National Park between Flamingo and Joe Bay. South Florida Research Center, Everglades National Park, Homestead, FL.

Olmsted, I., W.B. Robertson, Jr., J. Johnson and O.L. Bass, Jr. 1983. The vegetation of Long Pine Key. South Florida Research Center Report SFRC-83/05. Everglades National Park, Homestead, FL.

Olsen, J.D. and S. Burd. 1982. Marina utilities and codes. In: Goodwin R.F.(Ed.). *Boating and Moorage in the 1980's. Proceedings of a Workshop*, p. 88-95. Seattle, Washington.

Ostrenko, W. and F. Mazzotti. 1980. Small mammal populations in Melaleuca quinquenervia communities in the eastern Florida Everglades. In: R.K. Gieger (ed.) *Proceedings of the Melaleuca Symposium*, September 23-24, 1980. Florida Department of Agriculture and Consumer Services, Division of Forestry.

Palmisano, A.W., T. Joanen, and L. McNease. 1973. An analysis of Louisiana's 1972 experimental alligator harvest program. In: *Proceedings Annual Conference Southeast Association of Fish and Wildlife Agencies*, 27:184-206.

Parker, G.G. 1952. Geologic and hydrologic factors in the perennial yield of the Biscayne Aquifer. *Am. Water Works Assoc. Journal*, 43:817-843.

Parker, G.G. 1974. Hydrology of the pre-drainage system of the Everglades in south Florida. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past. Memoir 2,* Miami Geological Society, Miami, FL, pp. 18-27.

Parker, G.G. 1982. Aquifers of Florida. In: E.A. Fenald and D.J. Patton (eds). *Florida's Freshwater Atlas.* Tallahassee: Florida State University Press.

Parker, G.G. 1984. Hydrology of the pre-drainage system of the Everglades in southern Florida. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past II.* Miami Geological Society, Coral Gables, FL, pp 28-37.

Parker, G.G. and C.W. Cooke. 1944. Late cenozoic geology of southern Florida, with a discussion of the ground water. *Fla. Bur. Geol. Bull.*, 27.

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.

Parker, G.G. and N.D. Hoy. 1943. Further studies of geological relationships affecting soil and water conservation and use in the Everglades: I. Additional notes on the geology and ground water of southern Florida. *Soil Science Society of Florida Proc.*, 5-A:33-55.

Patrick, R. 1949. A proposed biological measure of stream conditions, based on a survey of the Conestoga Basin, Lancaster County, Pennsylvania. Academy of Natural Sciences, Philadelphia, Vol. 101, pp. 277-341.

Patrick, R. 1973. Use of algae, especially diatoms, in the assessment of water quality.In: Cairns, J., Jr. and K.L. Dickson (Eds.). *Biological Methods for the Assessment of Water Quality*, ASTM STP 528, pp. 76-95.

Patrick, R. 1977. Ecology of freshwater diatoms and diatom communities. In: Werner, D. (ed.). *The Biology of Diatoms.* Berkeley, California: University of California Press.

Patrick, R. and C.W. Reimer. 1966. *The Diatoms of the United States. Volume 1.* Academy of Natural Sciences, Philadelphia, Monograph Number 13, p. 688.

Paulson, D.R. 1966. The dragonflies (Odonata: Anisoptera) of southern Florida. Ph.D. Dissertation, University of Miami, Coral Gables, FL.

Pennak, R.W. 1978. *Freshwater Invertebrates of the U.S.*, 2nd Ed. New York:John Wiley and Sons. 803 pp.

Perkins, R.D. and P. Enos. 1968. Hurricane Betsy in the Florida-Bahamas area: Geologic effects and comparison with Hurricane Donna. *J. Geol.*, 76:710-717.

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.

Petuch, E.J. 1987. The Florida Everglades: a buried psuedoatoll? *Journal of Coastal Research*, 9:189-200.

Pfeuffer, R.J. 1985. Pesticide residue monitoring in sediment and surface water bodies within the South Florida Water Management District. Technical Publication 85-2. South Florida Water Management District, West Palm Beach, FL.

Pfeuffer, R.J. (in press). Pesticide residue monitoring in hydrosoil and surface within the South Florida Water Management District (draft report). South Florida Water Management District, West Palm Beach, FL.

Phillips, W.S. 1940. A tropical hammock on the Miami (Florida) Limestone. *Ecol.* 21:166-175.

Pilsbry, H.S. 1946. *Land mollusca of North America (North of Mexico). Volume II, Part I.* The Academy of Natural Sciences of Philadelphia, Monograph Number 3. Philadelphia, PA.

Pomeroy, L.R. 1970. The strategy of mineral cycling. *Ann. Rev. Ecol. and Systematics*, 1:171-190.

Poole, A. 1979. Sibling aggression among nestling ospreys, Pandion haliaetus, in Florida Bay, USA. *The Auk*, 96(2):415-417.

Poole, A. 1982. Brood reduction in temperate and sub-tropical ospreys, Pandion haliaetus. *Oecologia*, 53(1):111-119.

Poole, L.K. 1987. Florida's troublesome trio. *ENFO*. Vol. 87-4.

Pope, K.R. 1989. Vegetation in relation to water quality and hydroperiod on the Loxahatchee National Wildlife Refuge, (draft M.S. thesis), University of Florida, Gainesville, FL, 79 pp.

Pope, R.L., J.A. Browder and P.B. Schroeder. 1980. A study of the feasibility of using stomach contents analyses to determine food webs in the Everglades periphyton community. Contract PX52809. A report to Everglades National park from the South Florida Environmental Research Foundation, Miami, FL.

Porter, R.P. 1953. A contribution to the life history of the water rat, Neofiber alleni. Masters thesis, University of Miami, Coral Gables, FL.

Portnoy, J.W., R.M. Erwin and T.W. Custer. 1981. Atlas of gull and tern colonies: North Carolina to Key West, Florida (including pelicans, cormorants, and skimmers). FWS/OBS-80/05. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., 121 pp.

Powell, A.B., D.E. Hoss, W.F Hettler, D.S. Peters, L. Simoneaux and S. Wagner. 1987. Abundance and distribution of ichthyoplankton in Florida Bay and adjacent waters. Report Number SFRC-87/01. National Marine Fisheries Service.

Powell, G.V.N. 1987. Habitat use by wading birds in a subtropical estuary: Implications of hydrography. *Auk*, 104(4):740-749.

Powell, G.V.N. 1989. Relationships between hydrologic conditions and feeding habitat for roseate spoonbills and other wading birds in C-111 Basin. Annual report to South Florida Research Center, National Park Service, Everglades National Park, Homestead, FL.

Powell, G.V.N. and R. Bjork. 1989. Relationships between hydrologic conditions and quality and quantity of foraging habitat for roseate spoonbills and other wading birds in the C-111 basin. Annual report by National Audubon Society to South Florida Research Center, National Park Service, Everglades National Park, Homestead, FL.

Powell, G.V.N. and A.H. Powell. 1986. Reproduction by great white herons, Ardea herodias in Florida Bay USA as an indicator of habitat quality. *Biol. Conserv.*, 36(2):101-114.

Powell, G.V.N., R. Bjork, J.C. Ogden, R.T. Paul, A.H. Powell and W.B. Robertson. 1989 (in press). An analysis of population trends in some Florida Bay wading birds. *Wilson Bull.*

Powell, G.V.N., W.J. Kenworthy and J.W. Fourqurean. 1989. Experimental evidence for nutrient limitation of seagrass growth in a tropical estuary with restricted circulation. *Bull. Mar. Sci.*, 44(1):324-340.

Powell, G.V.N., S.M. Sogard and J.G. Holmquist. 1987. Ecology of shallow water bank habitats in Florida Bay. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL. 405 pp.

Pressler, E.D. 1947. Geology and occurrence of oil in Florida. *Am. Assoc. Petrol. Geol. Bull.*, 31(10):1851-1862.

Pritchard, P.C.H. 1978. *Rare and Endangered Biota of Florida: Vol. 1-Mammals, Vol. 2-Birds, Vol. 3-Amphibians & Reptiles, Vol. 4-Fishes.* Sponsored by the Florida Audubon Society and the Florida Defenders of the Environment, University of Florida, Gainesville, FL.

Puri, H.S. and R.O. Vernon. 1964. Summary of the geology of Florida and a guidebook to the classic exposures. *Florida Geological Survey*, Publication 5, revised., Tallahassee, FL.

Reark, J.B. 1961. Ecological investigations in the Everglades, Second annual report. Biology Department, University of Miami, Coral Gables, 19 pp.

Reddy, K.R. 1983. Soluble phosphorus release from organic soils. *Agric. Ecosys. Environ.*, 9:373-382.

Reddy, K.R. and P.S.C. Rao. 1983. Nitrogen and phosphorus fluxes from a flooded organic soil. *Soil Sci.*, 136:300-307.

Reeder, P.B. and S.M. Davis. 1983. Decomposition and nutrient uptake and microbial colonization of sawgrass and cattail leaves in Water Conservation Area 2A, Technical Publication 83-4. South Florida Water Management District, West Palm Beach, FL, 24 pp.

Rehm, A.E. 1974. A study of the marine algae epiphytic on the prop roots of Rhizophora mangle L. from Tampa to Key Largo, Florida. Ph.D. Dissertation, University South Florida, Tampa, FL, 183 pp.

Richardson, C.J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. *Science*, 228:1424-1427.

Richardson, J.R. and W.M. Kitchens. 1986a. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Second Quarter Report, May 1986, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and W.M. Kitchens. 1986b. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Third Quarter Report, September 1986, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and W.M. Kitchens. 1986c. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Annual Report, October 1, 1986- December 31, 1986, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and W.M. Kitchens. 1987. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Annual Report, October 1, 1986- September 30, 1987, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and W.M. Kitchens. 1988. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Annual Report, October 1, 1987- September 30, 1988, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and W.M. Kitchens. 1989. An evaluation of refuge habitats and relationships to water quality, quantity and hydroperiod. Annual Report, October 1, 1988- September 30, 1989, Research Order 32, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

Richardson, J.R. and D. S. Nichols. 1987. Ecological analysis of wastewater management criteria in wetland ecosystems. In: P.J. Godfrey, E.R. Kaynor, S. Pelczonski and J. Benforado (eds.). *Ecological considerations in wetlands treatment of municipal wastewater.* New York: Van Nostrand Reinhold., pp. 351-391.

Richardson, C.J., D.L. Tilton, J.A. Kadlec, J.P.M. Chami and W.A. Wentz. 1978. Nutrient dynamics of northern wetlands ecosystems. In: R.E. Good, D.F. Whigman and R.L. Simpson, (eds.). *Freshwater Wetlands: Ecological Processes and Management Potential.* Academic Press, pp. 217-241.

Rintz, R.E. and L.L. Loope. 1979. Vegetation map of Taylor Slough, Everglades National Park. Everglades National Park, Homestead, Florida.

Robbin, D.M. 1984. A new holocene sea level curve for the upper Florida Keys and Florida reef tract. In: Gleason, P.J., (ed.), *Environments of south Florida: present and past II.* Miami Geological Society, Coral Gables, Florida, pp. 437-458.

Robblee, M.B. 1989. Historical salinity studies in Florida Bay. Unpublished table. South Florida Research Center, Everglades National Park, Homestead, FL.

Robblee, M.B. and J.T. Tilmant. 1989 (abstract). Distribution, abundance and recruitment of the pink shrimp, (Penaeus duorarum), within Florida Bay. *Bull. Mar. Sci.*, 44(1):522. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Roberts, H.H., L.J. Rouse, Jr. and N.D. Walker. 1983. Evolution of cold water stress conditions in high latitude reef systems, Florida (USA) reef tract and the Bahama Banks (West Indies). *Caribb. J. Sci.*, 19 (1-2):55-60.

Roberts, H.H., L.J. Rouse, Jr., N.D. Walker and J.H. Hudson. 1982. Cold water stress in Florida Bay and northern Bahamas: A product of winter cold air outbreaks. *J. Sed. Petrol.*, 52(1):145-155.

Roberts, H.H., T. Whelan and W.G. Smith. 1977. Holocene sedimentation at Cape Sable, South Florida. *Sed. Geol.*, 18:25-60.

Robertson, W.B., Jr. 1953. A survey of the effects of fire in Everglades National Park. Unpublished report to the U.S. National Park Service, Department of the Interior.

Robertson, W.B., Jr. 1955. An analysis of the breeding bird populations of tropical Florida in relation to the vegetation. Ph.D. Dissertation, University of Illinois, Urbana.

Robertson, W.B., Jr. 1964. Freshwater supply and the nesting of the wood ibis in the southern Everglades. National Park Service, Everglades National Park, Homestead, FL. (Mimeogr.), 2 pp.

Robertson, W.B., Jr. 1989. The endangered species of Everglades National Park (unpublished manuscript). South Florida Research Center, Everglades National Park, Homestead, FL.

Robertson, W.B., Jr. and J.A. Kushlan. 1974. The southern Florida avifauna. In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past.* Miami Geological Society, Miami, FL.

Robertson, W.B., Jr. and J.A. Kushlan. 1984. The southern Florida avifauna. In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past.* Miami Geological Society, Coral Gables, Florida, pp. 219-257.

Robertson, W.B., Jr. and H.B. Muller. 1961. Wild winds and wildlife. *Audubon*, 63:308-311.

Robertson, W.B., Jr., L.L. Breen and B.W. Patty. 1983. Movement of marked roseate spoonbills in Florida with a review of present distribution. *J. Field Ornithol.*, 54:225-236.

Robertson, W.B., Jr., O.L. Bass and M. Britten. 1984. *Birds of Everglades National Park.* Published by Florida National Parks and Monuments Association.

Robinson, F.A. 1981. Relationship of Melaleuca to beekeeping. In: *Proceedings of Melaleuca Symposium*, September 23-24, 1980. Florida Division of Forestry, Department of Agriculture and Consumer Services, Tallahassee, FL, pp. 79-80.

Rockland, D.B. 1988. The economic impact of the sport and commercial fisheries of the Florida Keys. Report to the Everglades Protection Association, Florida Conservation Association and Monroe County Industrial Development Authority. Sport Fishing Institute, Washington, D.C., 107 pp.

Rodgers, J.A., S. Schwikert and A. Wenner. 1988. Status of the snail kite in Florida: 1981-1985. *American Birds*, 42(1):30-35.

Roessler, M.A. 1968. Observations on the seasonal occurrence and life histories of fishes in Buttonwood Canal, Everglades National Park. Ph.D. Dissertation, University of Miami, Coral Gables, FL.

Roessler, M.A. 1970. Checklist of fishes in Buttonwood Canal, Everglades National Park, Florida, and observations on the seasonal occurrence and life histories of selected species. *Bull. Mar. Sci.*, 20:860-893.

Roman, M.R., M.R. Reeve and J.L. Froggatt. 1983. Carbon production and export from Biscayne Bay, Florida. I. Temporal patterns in primary production, seston and zooplankton. *Estuary Coastal and Shelf Science*, 1:45-59.

Romans, Bernard. 1975. *A Concise Natural History of East and West Florida.* New York: Pelican Publishing Company Reprint.

Rose, P.W., M.D. Flora and P.C. Rosendahl. 1981. Hydrologic impacts of L-31 (W) on Taylor Slough, Everglades National Park. South Florida Research Center Report T-612. South Florida Research Center, Everglades National Park, Homestead, FL.

Rose, P.W. and P.C. Rosendahl. 1978. Annual hydrology review: Everglades National Park 1977. South Florida Research Center Report T-531. South Florida Research Center, Everglades National Park, Homestead, FL.

Rosendahl, P.C. and P.W. Rose. 1979. Water quality standards: Everglades National Park. *Environmental Management* 3(6):483-491.

Rosendahl, P.C. and P.W. Rose. 1982. Freshwater Flow rates and distribution within the Everglades marsh. In: Cross, R.D. and D.L. Williams, (Eds.) *Proceedings of the National Symposium on Freshwater Inflow to Estuaries*, Coastal Ecosystems Project, U. S. Fish and Wildlife Service, Washington, D.C., pp. 385-401.

Rouse, W.L. and J.B. Higman. 1964. Studies of the fish stocks in the Everglades National Park. VI. 1963-64. Annual report to the U.S. National Park Service by the Institute of Marine Sciences, University Miami, 34 pp.

Russell, G.M. 1986 (in press). Reconnaissance of landfill-generated plumes in low-relief areas, southeast Florida. U.S. Geological Survey, Tallahassee, FL.

Russell, R.P., L.L. Loope and T.C. Olmstead. 1980. Vegetation map of the coastal region between Flamingo and Joe Bay of Everglades National Park. National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL.

Rutherford, E.S., E.B. Thue and D.G. Buker. 1982. Population characteristics, food habits, and spawning activity of the spotted seatrout, Cynoscion nebulosus, in Everglades National Park, Florida. South Florida Research Center Report T-668. Everglades National Park, Homestead, FL.

Rutherford, E.S., E.B. Thue and D.G. Buker. 1983. Population structure, food habits, and spawning activity of gray snapper, Lutjanus griseus, in Everglades National Park. Everglades National Park, Report Number SFRC-83/02. South Florida Research Center, Homestead, FL, 50 pp.

Rutherford, E.S., T.W. Schmidt and J.T. Tilmant. 1986. Early life history of spotted seatrout, red drum, gray snapper, and snook in Everglades National Park, Florida. Technical Report Number SFRC-86/07. South Florida Research Center, Everglades National Park, Homestead, FL, 108 pp.

Rutherford, E.S., T.W. Schmidt and J.T. Tilmant. 1989. Early life history of spotted seatrout, Cynoscion nebulosus, and gray snapper, Lutjanus griseus, in Florida Bay, Everglades National Park, Florida. *Bull. Mar. Sci.*, 44(1):49-64.

Rutherford, E.S., J.T. Tilmant, E.B. Thue and T.W. Schmidt. 1987. Fishery harvest and population dynamics of gray snapper, Lutjanus griseus, in Florida Bay and adjacent waters. Unpublished report. South Florida Research Center, Everglades National Park, Homestead, FL, 30 pp.

Sanchez, C.A. 1987. Chapter 10. Phosphorus in the organic soils of the Everglades Agricultural Area. In: Izuno, F.T. and A.B. Bottcher (Eds.). *Final Report The Effects of On-Farm Agricultural Practices in the Organic Soils of the EAA on Nitrogen and Phosphorus Transport: Phase II*, (draft report). IFAS, University of Florida, Gainesville, FL.

Sanchez, C.A. 1988. Unpublished data. University of Florida Experiment Station, Belle Glade, FL.

Sanchez, C.A. 1989 (in press). Soil testing and fertilizer recommendations for crop production on organic soils. *University of Florida Experiment Station Bulletin.*

Sanchez, C.A. and H.W. Burdine. 1987. Relationship between soil test P and K levels and lettuce yield on Everglades histosols. *Soil and Crop Science Society of Fla. Proc.*, 47:52-56.

Sanchez, C.A. and P.S. Porter, 1988. Unpublished data. University of Florida Experiment Station, Belle Glade, FL.

Sanchez, C.A., P.S. Porter and G.H. Snyder. 1988. Phosphorus management in the EAA: critical soil properties. Research Proposal to South Florida Water Management District, West Palm Beach, FL.

Scheidt, D.J. 1988. Nutrient enrichment in the Everglades. *National Wetlands Newsletter*, 10(3):5-7.

Scheidt, D.J., M.D. Flora and D.R. Walker. 1987. Water quality management for Everglades National Park. In: *North American Lakes Management Society 7th International Symposium*, Orlando, Florida, November 4, 1987.

Schemnitz, S.D. 1972. Distribution and abundance of alligator, bear, deer, and panther in the Everglades region of Florida. Florida Game and Fresh Water Fish Commission. Ft. Lauderdale, FL, 26 pp. (Mimeogr.).

Schemnitz, S.D. 1974. Populations of bear, panther, alligator and deer in the Florida Everglades. *Florida Scientist*, 37(3): 157-167.

Schmidly, D.J. 1981. Marine mammals of the southeastern United States coast and the Gulf of Mexico. FWS/OBS-80/41. U.S. Fish and Wildlife Service, Office of Biological Service, Washington, D.C., 163 pp.

Schmidt, T.W. 1979. Ecological study of fishes and water quality characteristics of Florida Bay, Everglades National Park, Florida. Report Number RSP-EVER N-36. National Park Service, South Florida Research Center, Homestead, FL, 145 pp.

Schmidt, T.W. 1986. Food of young juvenile lemon sharks, Negaprion brevirostris, near Sandy Key, western Florida Bay USA. *Florida Scientist*, 49 (1):7-10.

Schmidt, T.W. 1989. Food habitats, length-weight relationship, and condition factor of young great barracuda, Sphyraena barracuda (Walbaum), from Florida Bay, Everglades National Park, Florida. *Bull. Mar. Sci.*, 44(1):163-170.

Schmidt, T.W. and G.E. Davis. 1978. A summary of estuarine and marine water quality information collected in Everglades National Park, Biscayne National Monument, and adjacent estuaries from 1879 to 1977. Report Number T-519. National Park Service, South Florida Research Center, Homestead, FL, 79 pp.

Schneider, J.J. and B.G. Waller. 1980. Summary of hydrologic data for the east Everglades, Dade County, Florida. Open File Report 80-1292. U.S. Geological Survey, Tallahassee, FL.

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.

Scholl, D.W. 1964a. Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: Part 1. *Mar. Geol.* 1:344-366.

Scholl, D.W. 1964b. Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: Part 2. *Mar. Geol.* 2:343-364.

Scholl, D.W. and M. Stuiver. 1967. Recent submergence of southern Florida: a comparison with adjacent coasts and eustatic data. *Geol. Soc. Am. Bull.*, 78:437-454.

Schroeder, M.C., H. Klein and N.D. Hoy. 1958. Biscayne aquifer of Dade and Broward counties, Florida. Florida Geological Survey Report of Investigations, Number 17.

Schwartz, A. 1952. The land mammals of southern Florida and the upper Florida keys. Ph.D. dissertation. University of Michigan. Ann Arbor, Michigan.

Scott, T.M. and M.S. Knapp. 1988. The Hawthorn Group of Peninsular Florida. Miami Geological Society, Memoir No. 3, Miami, FL.

Sculley, S.P. 1986. Frequency analysis of South Florida Water Management District rainfall. Technical Publication 86-6. South Florida Water Management District, West Palm Beach, FL, 69 pp.

Shafland, P.L. and J.M. Pestrak. 1982. Lower lethal temperatures for fourteen non-native fishes in Florida. *Env. Biol. Fish.*, 7:140-156.

Shaw, C. 1975. The pine and hammock forests of Dade County. Florida Division of Forestry report, Tallahassee, FL.

Shih, G. 1983. Data analysis to detect rainfall changes in south Florida. Technical Memorandum. South Florida Water Management District, West Palm Beach, FL.

Shih, S.F. 1988. Sugar cane yield, biomass, and water use efficiency. *Trans. of the American Soc. of Agricultural Engineers*, 31(1): 142-148.

Shih, S.F. and M. Rosen. 1985. Water table effects on nutrient contents of celery, lettuce and sweet corn. *Trans. of the American Soc. of Agricultural Engineers* 28(6):1867-1870.

Shinn, E.A. and E. Corcoran. 1988. Contamination by landfill leachate south Biscayne Bay, Florida. Final Report to Sea Grant, University of Miami. Miami, FL, 11 pp.

Shoemaker, A. (ed.). 1988. *Florida Statistical Abstracts.* Gainesville: University Press of Florida.

Shortemeyer, J.L. 1980. An evaluation of water management practices for optimum wildlife benefits in Conservation Area 3A. Florida Game & Fresh Water Fish Commission. Ft. Lauderdale, FL.

Simpson, R.H., N.L Frank and R.L Carrodus. 1969. The hurricane storm surge in south Florida. Environmental Sciences and Service Administration, Weather Bureau Report. National Hurricane Center, Miami, FL.

Skinner, R.H. 1988. Water quality results after C-111 fresh water release, John Pennekamp Coral Reef State Park. State of Florida Department of Natural Resources Memorandum to J. Stevenson, Chief, Bureau of Scientific and Technical Services.

Skrivan, J.A. and M.R. Karlinger. 1980. Semi-variogram estimation and universal kriging program. Computer Program Documentation User's Manual, Water Resources Division, U.S. Geological Survey, Washington, D.C.

Small, J.K. 1916. Royal Palm Hammock. *Journal of the New York Botanical Garden*, 16:165-172.

Small, J.K. 1929. *From Eden to Sahara, Florida's Tragedy*. Lancaster: Science Press Printing Co. 140 pp.

Small, J.K. 1932. *Manual of the Southeastern Flora*. Chapel Hill: University of North Carolina Press.

Small, J.K. 1933. An Everglades cypress swamp. *Journal of New York Botanical Garden*, 34:261-267.

Smith, A.J. and J.M. Vrieze. 1979. Population structure of Everglades rodents: responses to a patchy environment. *Journal of Mammalogy*, 60:778-794.

Smith, A.T. 1980. An environmental study of Everglades mink (Mustela vison). South Florida Research Center Technical Report T-555. Everglades National Park, Homestead, FL.

Smith, A.T. and D.M. Cary. 1982. Distribution of the Everglades mink. *Florida Scientist*, 45(2): 106-112.

Smith, B. 1948. Report on reconnaissance of the Everglades. Report made to the Secretary of the Treasury.

Smith, F.G.W., R.H. Williams and C.C. Davis. 1950. A ecological survey of the subtropical inshore waters adjacent to Miami. *Ecology*, 31:119-146.

Smith, T.J., III, J.H. Hudson, M.B. Robblee, G.V.N. Powell, and P.J. Isdale. 1989. Freshwater Flow from the Everglades to Florida Bay: A historical reconstruction based on fluorescent banding in the coral Solenastrea bournoni. *Bull. Mar. Sci.* 44(1):274-282.

Snyder, G.H. 1987. (Ed.), Agricultural Flooding of organic soils, Technical Bulletin 870. Agricultural Experiment Station, IFAS, University of Florida. Gainesville, Florida.

Snyder, J.R. 1986. The impact of wet season and dry season prescribed fires on Miami rock ridge pineland, Everglades National Park. South Florida Research Center Report SFRC 86/06, Everglades National Park, Homestead, FL.

Snyder, G.H., H.W. Burdine, J. R. Crockett, G.J. Gascho, D.S. Harrison, G. Kidder, J.W. Mishoe, D.L. Myhre, F.M. Pate and S.F. Shih. 1978. Water table management for organic soil conservation and crop production in the Florida Everglades. Florida Agricultural Experiment Station Bulletin 801. Gainesville, FL.

Snyder, N.F.R. and H.A. Snyder. 1969. A comparative study of mollusc predation by limpkins, Everglades kites, and boat-tailed grackles. *Living Bird*, 8:177-233.

Soil Conservation Service. 1958. Soil survey (detailed reconnaissance) of Dade County, Florida. Soil Survey Series 1947, Number 4, U.S. Department of Agriculture.

South Florida Business Journal. 1989. Commercial fishing in the Florida Keys. January 2 and January 9 editions.

South Florida Research Center. 1989. Technical and management reports. U.S. Department of the Interior, National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL.

South Florida Water Management District. 1978. Why a drawdown of Conservation Area 2A? Public Information Office, South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1982. An analysis of water supply backpumping for the lower east coast planning area. South Florida Water Management District. West Palm Beach, FL.

South Florida Water Management District. 1982. Report on Tropical Storm Dennis-August 16-18, 1981. South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1983. Water quality management plan for the S-2 and S-3 drainage basins in the Everglades Agriculture Area. South Florida Water Management District. West Palm Beach, FL.

South Florida Water Management District. 1983. Contract No. 66/0408BBBMA, Memorandum of Agreement between the Florida Department of Environmental Regulation (DER) and The Board of Trustees of the Internal Improvement Trust Fund (TIITF) and the South Florida Water Management District (SFWMD) and the Florida Game and Fresh Water Fish Commission (FGFWFC) Concerning the Holey Land and Rotenberger Project, dated May 13, 1983.

South Florida Water Management District. 1984a. Water management planning for the western C-51 basin. South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1984b. North New River backpumping water quality impact study. Report No. 1. Preconstruction and initial operation. South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1987. Staff manual for the management of water shortages. South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1989a. Save our rivers - five year plan. South Florida Water Management District, West Palm Beach, Florida.

South Florida Water Management District. 1989b. Unpublished summary tables of Everglades National Park water quality annual averages for inflow stations. Water Quality data base, South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1989c. Interim Surface Water Improvement and Management Plan for Lake Okeechobee, South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District. 1990. Monitoring and operating plan for the C-111 Canal interim construction project. In: *Appendix 7, Vegetation, water quality, hydrology, estuarine salinity and productivity in the C-111 Basin* (in press). South Florida Water Management District, West Palm Beach, FL.

Sowder, A. and S.L. Woodall. 1985. Small mammals of Melaleuca stands and adjacent environments in southwestern Florida. *Florida Scientist,* 48:44-46.

Spackman, W., D.W. Scholl and W.H. Taft. 1964. Field guide book to the environments of coal formation in southern Florida: Geological Society of America Pre-convention Field trip, Nov. 16-18,1964, 67 pp.

Spangler, F.L., W.E. Sloey, and C.W. Fetter,Jr. 1976. Artificial and natural marshes as wastewater treatment systems in Wisconsin. In: *Freshwater Wetlands and Sewage Effluent Disposal.* University of Michigan, Ann Arbor, Michigan, pp. 215-240.

Sprangers, J. 1980. Ecological correlates of sexual dimorphism in the boat-tailed grackle, Cassidix major (Aves: Icteridae). Masters thesis, University of Miami. Coral Gables, Florida.

Sprunt, A., Jr. 1954. *Florida Bird Life.* New York: Coward-McCann, Inc., and National Audubon Society.

Sprunt, A. IV and M.P. Kahl. 1960. Mysterious Mycteria: Our American stork. *Audubon,* 62:206-209, 234, 252.

Steiner, T.M., O.L. Bass, Jr. and J.A. Kushlan. 1983. Status of eastern indigo snake in southern Florida. National Parks and vicinity. South Florida Research Center Report SFRC-83/01. Everglades National Park, Homestead, FL.

Stephans, D.W. and M.E. Jennings. 1976. Determination of primary productivity and community metabolism in streams and lakes using diel oxygen measurements. Computer Program Documentation User's Manual Program Number J330. U.S. Geological Survey. Water Resource Division, Gulf Coast Hydroscience Center, Bay, St. Louis, Ms.

Stephens, A.R. 1943. Progress report on the topographic reconnaissance of the Everglades Drainage District. *Soil Sci. Soc. Fl. Proc.,* 5: 24-32.

Stephens, J.C. 1955. Drainage of peat and muck lands In: *Yearbook of agriculture for 1955.* U.S. Department of Agriculture, Washington, D.C., pp. 539-557.

Stephens, J.C. 1969. Peat and muck drainage problems, Proc. paper 6603. *Journal of the Irrigation and Drainage Division,* American Society of Civil Engineers. Volume 95, Number IR2, pp. 285-305.

Stephens, J.C. 1974. Subsidence of organic soils in the Florida Everglades-a review and update. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past.* Miami Geological Society, Miami, FL, pp. 352-361.

Stephens, J.C. and L. Johnson. 1951. Subsidence of organic soils in the upper Everglades region of Florida. *Soil Sci. Soc. Fl., Proc.,* 11:191-237.

Steward, K.K. 1974. Physiological, edaphic and environmental characteristics of Everglades saw grass communities. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past.* Miami Geological Society, Miami, FL, pp. 37-46.

Steward, K.K. and W.H. Ornes. 1975a. The autecology of sawgrass in the Florida Everglades. *Ecology*, 56:162-171.

Steward, K.K. and W.H. Ornes. 1975b. Assessing a marsh environment for wastewater renovation. *Journal of WPCF*, 47:1880-1891.

Stieglitz, W.O. 1962. Pest plant status report, Loxahatchee National Wildlife Refuge, unpublished mimeogr. report, Loxahatchee National Wildlife Refuge, Boynton, Beach, FL, 4 pp.

Stieglitz, W.O. 1964. A status report of the vegetation of the Loxahatchee National Wildlife Refuge (Conservation Area no. 1), unpublished mimeogr. report, Loxahatchee National Wildlife Refuge, Boynton Beach, FL, 12 pp.

Stieglitz, W.O. 1965. Status report of water hyacinth, alligator weed and water lettuce on the Loxahatchee National Wildlife Refuge, September 2, 1965, unpublished mimeogr. report, Bureau of Sport Fisheries and Wildlife, Division of Refuges, USFWS, Boynton Beach, FL, 19 pp.

Stocker, R.K. and D.R. Sanders. 1981. Chemical control of Melaleuca quinquenervia. In: Geiger, R.K. (Ed.). *Proceedings of Melaleuca Symposium*, September 23-24, 1980. Florida Division of Forestry, Department of Agriculture and Consumer Services, Tallahassee, FL.

Stockman, K.W., R.N. Ginsburg and E.A. Shinn. 1967. The production of lime mud by algae in south Florida. *J. Sed. Petrol.*, 37(2):633-648.

Stoneburner, D.L. and J.A. Kushlan. 1984. Heavy metal burdens in American crocodile, Crocodylus acutus, eggs from Florida Bay, Florida USA. *J. Herpetol.*, 18 (2):192-193.

Swart, P. 1989a. Presentation to Southeast Florida Chapter of the Geological Society of America. Fall 1989.

Swart, P. 1989b. Assistant professor of Marine Science, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Virginia Key, Florida. Phone conversation October 19, 1989. Data on growth rings in corals from Ceasars Creek, Florida.

Swift, D. R. 1981. Preliminary investigations of periphyton and water quality in the Everglades water conservation areas. Technical Publication 81-05. South Florida Water Management District, West Palm Beach, FL.

Swift, D.R. 1984. Periphyton and water quality relationships in Everglades Water Conservation Areas. In: Gleason, P.J. (Ed.). *Environments of South Florida: Present and Past.* Miami Geological Society, Coral Gables, FL, pp.97-117.

Swift, D.R. 1986. Baseline water quality conditions and periphyton community structure in WCA-3B, July 1982-November 1983. Unpublished technical memorandum. South Florida Water Management District, West Palm Beach, FL.

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.

Sykes, P.W., Jr. 1983. Snail kite use of the freshwater marshes of south Florida. *Florida Field Naturalist* 11:73-88.

Tabb, D.C. 1963. A summary of existing information on the freshwater, brackish water, and marine ecology of the Florida Everglades region in relation to freshwater needs of Everglades National Park. Report 630609. University Miami Marine Laboratory, Miami, FL.

Tabb, D.C. 1966. The effects of changes in water supply in marshes on the species composition of fishes. Annual Report to Bureau of Sport Fisheries and Wildlife. Contract No. 14-16-004-56.

Tabb, D.C. 1967. Prediction of estuarine salinities in Everglades National Park, Florida, by the use of ground water records. Ph.D. dissertation, University Miami, Coral Gables, FL, 107 pp.

Tabb, D.C., T.R. Alexander, T.M. Thomas and N. Maynard. 1967. The physical, biological and geological character of the area south of C-111 canal in extreme southeastern Everglades National Park. Report to the U.S. National Park Service, Institute of Marine Sciences, University of Miami, Miami, FL.

Tabb, D.C., B. Drummond and N. Kenny. 1974. Coastal marshes of southern Florida as habitat for fishes and effects of changes in water supply on these habitats. Final report to Bureau Sport Fish Wildlife (Contract No. 14-16-004-56) Rosenstiel School Marine Atmospheric Science, University of Miami, Miami, FL.

Tabb, D.C., D.L. Dubrow and R.B. Manning. 1962. The ecology of northern Florida Bay and adjacent estuaries. *Technical Series of Florida Board Conservation* 39:1-79.

Tabb, D.C. and R.B. Manning. 1961. A checklist of the flora and fauna of northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July 1957 through September 1960. *Bull. Mar. Sci. Gulf Caribb*, 11(4):552-649.

Tabb, D.C. and R.B. Manning. 1962. A checklist of the flora and fauna of northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July 1957 through September 1960. *Bull. Mar. Sci. Gulf Caribb.*, 11(4):552-649.

Tate, R.L. III. 1979. Effect of Flooding on microbial activities in organic soils: carbon metabolism. *Soil Sci.*, 128:267-273.

Taylor, D.L. 1981. Fire history and fire records for Everglades National Park 1948-1979. South Florida Research Center Report T-619. Everglades National Park, Homestead, FL.

Taylor, D.L. 1983. Fire management and the Cape Sable seaside sparrow. T. Quay (Ed.). *Seaside sparrows*. Raleigh: University of North Carolina Press.

Taylor, D.L., and A. Herndon. 1981. Impact of 22 years of fire on understory hardwood shrubs in slash pine communities within Everglades National Park. South Florida Research Center Report T-640. Everglades National Park, Homestead, FL.

Tchobanoglous, G. 1979. *Wastewater Engineering: Treatment, Disposal, Reuse.* Second ed . New York: McGraw-Hill.

Terry, R.E. 1980. Nitrogen mineralization in Florida histosols. *Soil Sci. Soc. Am. J.*, 44:747-750.

Terczak, E.F. 1980. Aquatic macrofauna of the Water Conservation Areas. September 1979-1980, unpublished data. South Florida Water Management District, West Palm Beach, FL.

Thayer, G.W., W.F. Hettler, Jr., A.J. Chester, D.R. Colby and P.J. McElhaney. 1987. Distribution and abundance of fish communities among selected estuarine and marine habitats in Everglades National Park. Report Number SFRC-87/02. National Marine Fisheries Service, South Florida Research Center, Everglades National Park, Homestead, FL, 166 pp.

Thomas, T.M. 1970. A detailed analysis of climatological and hydrological records of south Florida with reference to man's influence upon ecosystem evolution. Report DI-NPS-14-10-1-160-18 to U.S. National Park Service, University of Miami, Coral Gables, FL.

Thomas, T.M. 1974. A detailed analysis of climatological and hydrological records of south Florida, with reference to man's influence upon ecosystem evolution, In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past.* Miami Geological Society, Miami, FL, pp. 82-122.

Thue, E.B., E.S. Rutherford and D.G Buker. 1982. Age, growth and mortality of the common snook, Centropomus undecimalis (Bloch), in Everglades National Park, Florida. South Florida Research Center, Report Number T-683. National Park Service, Everglades National Park, Homestead, FL.

Tilmant, J.T. 1975. Habitat utilization by round-tailed muskrats, Neofiber alleni, in Everglades National Park. M.S. Thesis, Humboldt State University, Arcata, California.

Tilmant, J.T. 1989. A history and an overview of recent trends in the fisheries of Florida Bay. *Bull. Mar. Sci.*, 44(1):3-22.

Tilmant, J.T., E.S. Rutherford and E.B. Thue. 1989 (abstract). Fishery harvest and population dynamics of the common snook, (Centropomus undecimalis), from Florida Bay and adjacent waters. *Bull. Mar. Sci.*, 44(1):523. Presented at Symposium on Florida Bay, a Subtropical Lagoon. U.S. National Park Service/Everglades National Park and University of Miami/Rosenstiel School of Marine and Atmospheric Science. 1-5 June 1987.

Toops, C.M. and W.E. Dilley. 1986. *Birds of south Florida, an interpretive guide.* Conway, Arkansas: River Road Press.

Toth, L.A. 1987. Effects of hydrologic regimes on lifetime production and nutrient dynamics of sawgrass. Technical Publication 87-6. South Florida Water Management District, West Palm Beach, FL, 32 pp.

Toth, L.A. 1988. Cattail nutrient dynamics. Technical Publication 88-06. South Florida Water Management District, West Palm Beach, FL.

Trimble, P. 1986. South Florida regional routing model. Technical Publication 86-3. South Florida Water Management District, West Palm Beach, FL, 147 pp.

Turney, W.J. and B.F. Perkins. 1972. Sedimenta III: Molluscan distribution in Florida Bay. Comparative Sedimentology Laboratory, University Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, FL, 37 pp.

Urban, N.H. 1984 (abstract). Invertebrate colonization of sawgrass and cattail leaf litter during two years of decomposition in the Everglades. *Florida Scientist,* Volume 47, Supplement 1. Presented at the March 29-31, 1984 meeting at Florida Atlantic University, Boca Raton, FL.

U.S. Army Corps of Engineers. 1961. Survey review report, Central and South Florida Project, South Dade County. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL.

U.S. Army Corps of Engineers. 1963. General design memorandum, South Dade County. U.S. Army Corps of Engineers. Jacksonville District, Jacksonville, FL.

U.S. Army Corps of Engineers. 1985. General plan for implementation of an improved water delivery system to Everglades National Park. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL.

U.S. Army Corps of Engineers. 1988. Central and southern Florida project for Flood control and other purposes. Part V - Coastal areas south of St. Lucie Canal. Supplement 37 - General Design Memorandum south Dade County, Addendum 2-- Canal 111. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL, 55 pp.

U.S. Congress, Senate. 1895. Annual Report of the Chief of Engineers to Congress on the Improvement of the Caloosahatchee River, Florida. 54th Congress, 1st Session. P. 1549.

U.S. Congress, Senate. 1892. Annual Report of the Chief of Engineers to Congress on the Improvement of the Caloosahatchee River, Florida. 52nd Congress, 2nd Session. P. 1377.

U.S. Congress, Senate. 1970. River basin monetary authorizations and miscellaneous civil works amendments. U.S. Senate Report No. 91-895. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of the Interior. 1979. The Everglades: a map at 1:52,800 scale. National Park Service.

U.S. Department of the Interior. 1989. An evaluation of habitat improvements and wildlife benefits from the U.S. Army Corps of Engineer's proposed Shark Slough General Design Memorandum. U.S. National Park Service-South Florida Research Center, Everglades National Park, Homestead, FL.

U.S. Environmental Protection Agency. 1981. Analysis of wastewater discharges from marine sanitation devices. Report by JRB Associates, Inc. to the Office of Analysis and Evaluation, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1985. Coastal marinas assessment handbook, Chap. 4.0 - Environmental impacts. U.S. Environmental Protection Agency, Region IV, Atlanta, GA.

U.S.Fish and Wildlife Service. 1952. A quantitative study of the major plant communities of Loxahatchee Refuge, FL. Arthur R. Marshall Loxahatchee National Wildlife Refuge, U.S. Dept. of the Interior, U.S. Fish and Wildlife Service, Boynton Beach, FL, 8 pp.

U.S. Fish and Wildlife Service. 1972. A report on fish and wildlife resources affected by water regulation schedule for Loxahatchee National Wildlife Refuge (Conservation Area 1), Florida, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Boynton Beach, FL.

U.S. Fish and Wildlife Service. 1984. Fire Management Plan, Loxahatchee National Wildlife Refuge, Boynton Beach, FL. U.S Department of the Interior, U.S. Fish and Wildlife Service,.National Wildlife Refuge System.

U.S. Fish and Wildlife Service. 1985. Melaleuca control study progress report, Loxahatchee National Wildlife Refuge. U.S Department of the Interior, U.S. Fish and Wildlife Service,.Bureau of Sport Fisheries and Wildlife, Boynton Beach, FL.

U.S. Fish and Wildlife Service. 1989. Arthur R. Marshall Loxahatchee NWR Melaleuca control plan (draft). Arthur R. Marshall Loxahatchee National Wildlife Refuge, U.S Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Boynton Beach, FL.

U.S. National Park Service. 1971. Appraisal of water quality needs and criteria for Everglades National Park, U.S. National Park Service, U.S. Department of the Interior.

U.S. National Park Service. 1979. Draft Master Plan, Everglades National Park. U.S. Department of the Interior, U.S. National Park Service, U.S. Government Printing Office 1977-777-033/28.

U.S. National Park Service. 1989. An evaluation of habitat improvements and wildlife benefits from the U.S. Army Corps of Engineer's proposed Shark Slough General Design Memorandum. U.S. National Park Service, South Florida Research Center,Everglades National Park, Homestead, FL.

Van Arman, J. 1984. South Florida's estuaries, In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past.* Miami Geological Society, Coral Gables, Florida, pp. 79-96.

Vandiver, V.V. 1981. Melaleuca in Florida. Circular A-81-7. IFAS, University of Florida, Gainesville, FL.

Van Meter, N. 1965. Some quantitative and qualitative aspects of periphyton in the Everglades. M.S. Thesis, University of Miami, Coral Gables, Florida.

Van Meter-Kasanov, N. 1973. Ecology of the micro-algae of the Florida Everglades, Part 1 -- Environment and some aspects of freshwater periphyton, 1959 to 1963. *Nova Hedwigia*, 24:619-664.

Volk, B.G. 1973. Everglades histosol subsidence: 1. CO_2 evolution as affected by soil type, temperature and moisture. *Soil & Crop Sci. Soc. of Fla. Proc.*, 32:132-135.

Volk, B.G., S.D. Schemnitz, J.F. Gamble and J.B. Sartain. 1975. Baseline data on Everglades soil-plant systems: Elemental composition, biomass and soil depth. In: Howell, F.G., Gentry, J.R. and M.H. Smith (Eds.) *Mineral Cycling in Southeastern Ecosystems*. Available as CONF-740513, NTIS, U.S. Department of Commerce, Springfield, Va.. pp. 658-672.

Wade, D.D., J.J. Ewel and R. Hofstetter. 1980. Fire in south Florida ecosystems. General Technical Report SE-17. U.S. Department of Agriculture Forest Service, Asheville, N.C.

Wagner, J.I. and P.C. Rosendahl. 1987. History and development of water delivery schedules for Everglades National Park through 1982. South Florida Research Center Report, Everglades National Park, Homestead, FL.

Waller, B.G. 1975. Distribution of nitrogen and phosphorus in the Conservation Areas of south Florida July 1972 to June 1973. Water Resources Investigation 5075, U.S. Geological Survey, Tallahassee, FL.

Waller, B.G. 1976. Analysis of selected benthic communities in Florida Everglades with reference to their physical and chemical environments. Water Resources Investigation 76-38, U.S. Geological Survey, Tallahassee, FL.

Waller, B.G. 1981. Water quality data for selected stations in the East Everglades, Florida. Open File Report 81-821. U.S. Geological Survey, Tallahassee, FL.

Waller, B.G. 1982a. Water quality characteristics of Everglades National Park, 1959-1977, with reference to the effects of water management. Water Resources Investigation 82-34. U.S. Geological Survey, Tallahassee, FL.

Waller, B.G. 1982b. Effects of land use on surface water quality in the East Everglades, Dade County, Florida. Water Resources Investigations 81-59. U.S. Geological Survey, Tallahassee, FL.

Waller, B.G. 1983. Effects of land use on ground water quality in the East Everglades, Dade County, Florida. U.S. Geological Survey, Water Resources Investigation 82-4093. Tallahassee, FL.

Waller, B.G. and J.E. Earle. 1975. Chemical and biological quality of water in part of the Everglades, southeastern Florida. Water Resources Investigations 56-75. U.S. Geological Survey, Tallahassee, FL. 157 pp.

Watts, W.A. 1971. Postglacial and interglacial vegetation history of southern Georgia and central Florida. *Ecology*, 52:676-690.

Werner, H.W. 1976. Distribution, habitat, and origin of the Cape Sable seaside sparrow. Masters thesis. University of South Florida, Tampa, FL.

Werner, H.W. and G.E. Woolfenden. 1983. The Cape Sable sparrow: its habitat, habits and history. In: T.L. Quay, J.B. Funderburg, Jr., D.S. Lee, E.F. Potter, and C.S. Robbins, (Eds.) *Proceedings of the Seaside Sparrow, its Biology and Management Symposium*. North Carolina Biological Survey and State Museum, pp. 55-75.

Wetzel, R.L. (Ed.) Methods and measurements of periphyton communities: a review. STP 690, American Society for Testing and Materials, Philadelphia, Pa., 183 pp.

White, W.A. 1970. The geomorphology of the Florida peninsula. *Florida Bureau of Geology Bulletin Number 51*.

Whittaker, L. Personal Communication. Park Service Botanist, Everglades National Park, Homestead, FL.

Wiggins, T.S. and A.B. Bottcher. 1987. Chap. 3. Water quality in the EAA soils and water conveyance system, Lake Okeechobee, and water conservation areas. In: Izuno, F.T. and A.B. Bottcher, (Eds). *The effects of on-farm agricultural practices on the organic soils of the Everglades Agricultural Area on nitrogen and phosphorous transport: Phase II.*, (unpublished draft report). IFAS, University of Florida, Gainesville, FL.

Willoughby, H.L. 1898. *Across the Everglades, a Canoe Journey of Exploration.* London:J.M. Dent & Co.

Wilson, D.D. and L. Porras. 1983. The ecological impact of man on the south Florida herpetofauna. Special Publication Number 9. University of Kansas, Museum of Natural History. Manhattan, Ks.

Wilson, S.U. 1974. Metabolism and biology of a blue-green algal mat. M.S. thesis, University of Miami, Coral Gables, Florida.

Wood, E.J.F. and N.G. Maynard. 1974. Ecology of the micro-algae of the Florida Everglades. In: Gleason, P.J. (Ed.) *Environments of South Florida: Present and Past.* Miami Geological Society, Miami, FL, pp. 123-145.

Wood, J.M. and G.W. Tanner. 1989. Graminoid community composition and structure within four Everglades management areas (draft report). Department of Wildlife and Range Sciences. University of Florida, Gainesville, FL.

Woodall, S.L. 1978. Melaleuca in Florida: a progress report on research by the U.S. Forest Service, Forest Resources Laboratory, Lehigh Acres, FL.

Woodall, S.L. 1983. Establishment of Melaleuca quinquenervia seedlings in the pine-cypress ecotone of Southwest Florida. *Florida Scientist*, 46:65-72.

Woodward, A.R., D.N. David and T.C. Hines. 1987. American alligator management in Florida. In: Odom, R.R., K.A. Fiddleberger, and S.C. Ozier. *Proc. 3rd Southeast Non-game and Endangered Wildlife Symposium*, Athens, GA. Pages 98-113.

Woodward, A.R., M.L. Jennings and H.F. Percival. 1989. Egg collecting and hatch rates of American alligator eggs in Florida. *Wildlife Society Bulletin*, 17:124-130.

Woodley, W.L. 1970. Precipitation results from a pyrotechnic cumulus seeding experiment. *J. Appl. Meterol.*, 9:242-257.

Woodley, W. L., A. Olsen, A. Herndon and V. Wiggert. 1974. Optimizing the measurement of convective rainfall in Florida. National Oceanic and Atmospheric Administration Technical Memorandum ERL WMPO-18-1-98. Miami, Florida.

Worth, D. 1983. Preliminary environmental response to marsh dewatering and reduction in water regulation schedule in Water Conservation Area-2A, September 1983. Technical Publication 83-06. South Florida Water Management District, West Palm Beach, FL.

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.

Yates, S.A. 1974. An autecological study of sawgrass, Cladium jamaicense in southern Florida. Masters thesis, Department of Biology, University of Miami, Coral Gables, Florida., 93 pp.

Young, F.N. 1954. *The Water Beetles of Florida*. Gainesville: University of Florida Press.

Zaffke, M. 1983. Plant communities of Water Conservation Area 3A; baseline documentation prior to the operation of S-339 and S-340. Technical Memorandum. South Florida Water Management District, West Palm Beach, FL. 31 pp.

Zaffke, M. 1984. Wading bird utilization of Lake Okeechobee marshes, 1977-1981. Technical Publication 84-9. South Florida Water Management District, West Palm Beach, FL, 38 pp.

Zale, A.V. and R. Mulholland. 1985. Habitat suitability index models: laughing gull. *U.S. Fish and Wildlife Service Biological Report* 82(10.94), 23 pp.

Zieman, J.C. 1982. The seagrass ecosystems of South Florida: A community profile. FWS/OBS-82/25. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., 125 pp.

Zieman, J.C. and J.W. Fourqurean. 1985. The distribution and abundance of benthic vegetation in Florida Bay, Everglades National Park. Contract Number CX5280-2-2204. South Florida Research Center, Everglades National Park, Homestead, FL.

Zieman, J.C., G.W. Thayer, M.B. Robblee and R.T. Zieman. 1979. Production and export of sea grasses from a tropical bay. In: Livingston, R.J. (Ed.). *Ecological Processes in Coastal and Marine Systems*, Florida State University, Tallahassee, FL.

Zillioux, E. 1978. A coastal mangrove system in transition. I. History of freshwater runoff and its effects upon zooplankton recruitment. Unpublished manuscript 53 pp.

This Page Intentionally Left Blank